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MISSISSIPPIAN GAS SANDS OF CENTRAL MICHIGAN AREA[1]

EDWARD W. HARD[2]
Mattoon, Illinois

ABSTRACT

Since 1929 many important gas fields have been discovered in the central part of the Southern Peninsula of Michigan. These fields are on three main northwest-striking anticlines and produce from rocks of Mississippian age. The major problems are the stratigraphy of the gas sands and the relation of gas production in the Michigan formation to oil production in the Dundee, where the two (on the same general structure) are not directly superposed.

The term "stray sand" was first applied to the gas-producing stratum in the Clare field because the sand was believed to be of Michigan age rather than Marshall, as had been previously supposed. A diastem or unconformity between the Michigan and Marshall formations was postulated on evidence found in the eastern part of the state, even though no petrological distinction was recognized between the "stray sand" and the upper strata of the Marshall. It was suggested that the "stray" might be reworked Marshall sand deposited on flanks of islands in the Michigan seas.

After detailed examination of all the available information that could be assembled, it is concluded that the gas sands in the various fields are not all of the same stratigraphic horizon. The stray sands in the eastern part of the state appear to be a facies and close time equivalent of the upper part of the Marshall farther west. The break which is postulated in the eastern part of the state does not seem to extend to the fields in the west-central part, hence some of the gas sands are apparently of Marshall age.

Available evidence shows that the most important factor in limiting gas occurrence is the regional structure, although variations in sand thickness and depositional structures are locally important. Pre-Marshall structure apparently controls Dundee oil production locally, for the "Marshall to Dundee interval" is thinnest over the oil-producing areas.

Regional correlations suggest that the lower Michigan and upper Marshall formations are a part of a deltaic or littoral deposit, and that the lower part of the Michigan formation in the eastern part of the area studied is an off-shore phase of the upper part of the Marshall farther west.

Dark-colored shales in the Michigan or Coldwater formation may have been source beds for the gas in the central Michigan area. The lack of commercial gas in Mississippian rocks in the southeastern part of the area is explained by a paucity of bituminous matter in the dark shales due, possibly, to near-shore deposition.

[1] A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the University of Michigan, April, 1937. Revised, October, 1937. Manuscript received, November 3, 1937.

[2] Sun Oil Company.

Introduction

AREA DISCUSSED AND SCOPE OF PAPER

Following the development of the Saginaw oil field in 1925 and 1926, wildcat drilling primarily in search of oil led to the discovery of a number of important gas fields in the central part of the Southern Peninsula of Michigan. These fields produce from rocks of Mis-

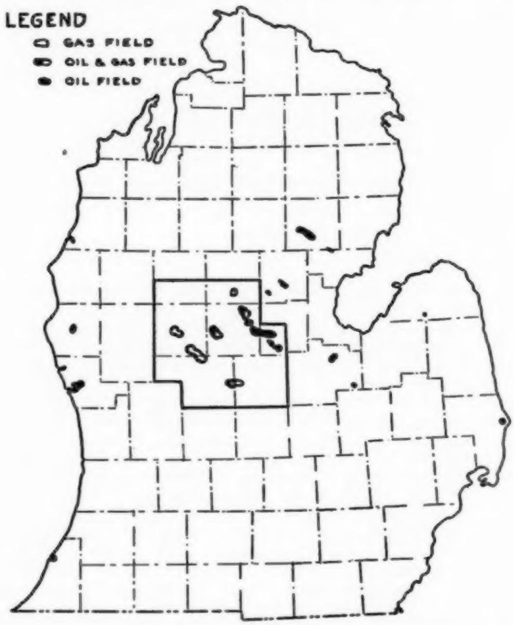


FIG. 1.—Outline map of Southern Peninsula of Michigan showing location of principal oil and gas fields and area studied.

sissippian age at depths ranging from 800 to 1,500 feet. Some wells have had an estimated initial open flow as high as 60 million cubic feet per day, but the average is probably less than 10 million.

The fields lie in an area extending approximately 40 miles northwest and southeast and 30 miles northeast and southwest, an area that includes parts of Clare, Isabella, Gratiot, Mecosta, Midland, and Montcalm counties (Fig. 1 and Fig. 16). Gas production is generally confined to three parallel folds which cross the area about 15 miles apart. The Clare, Vernon, and Leaton fields are on the northeastern fold, the Broomfield field on the central fold, and the Crys-

tal-New Haven, Six Lakes, and Austin fields on the southwestern fold. On this basis the fields are conveniently grouped for study since the important lateral stratigraphical changes take place at right angles to the folds.

The purpose of this paper is two-fold: (1) to study the stratigraphy and origin of the gas sands and their significance to gas occurrence; (2) to determine the relation of gas production in the Mississippian to oil production in the Devonian where the two producing areas are not directly superimposed although on the same general "high."

RECOGNITION OF "STRAY SAND"

As originally described the Marshall group of the Mississippian was separated into two divisions—the upper Marshall or Napoleon sandstone, and the lower Marshall. Early well logs in Saginaw County, however, revealed the fact that in this area there were three recognizable units, the upper two composed of light-colored sandstone and the lower of red sandstone and shales.

In 1929 the discovery well of the Clare gas field and of Mississippian gas production in central Michigan was completed with an open flow of approximately 3 million cubic feet per day. It was thought to be producing from the Napoleon sandstone until a deeper offset penetrated 40–50 feet of sandy dolomite, limestone, shale, and gypsum between the producing sand and a lower sandstone that more nearly resembled the Napoleon. As the intervening layers were similar to the overlying Michigan formation, it was believed that the gas sand belonged to the Michigan rather than to the Marshall. Subsequently the term "stray sand"[3] was applied to this gas-producing stratum.

PREVIOUS WORK

Since that time there has been considerable discussion in regard to the correlation and stratigraphy of the gas sands. Thomas[4] in 1931, after examining core data in the eastern part of the state, suggested a tripartate division of the Marshall. He proposed using the term "Upper Marshall" to denote a sandstone member equivalent to the stray sand in the Clare, Vernon, and Leaton area, and retaining the terms "Napoleon" for the continuous light-colored sandstone below this but near the top of the formation, and "Lower

[3] As the term "stray" is extensively used in the paper, the quotation marks will be omitted hereafter.

[4] W. A. Thomas, "A Study of the Marshall Formation in Michigan," *Michigan Acad. Sci., Arts, and Letters*, Papers, Vol. 14 (1931), p. 493.

Marshall" for the underlying red sands and shales. Stearns and Cook[5] in 1932, after a petrographic study of the stray sands and Marshall formations, were unable to find any distinctive differences between them. Newcombe in 1932,[6] and again in 1935,[7] in regional studies of the oil and gas fields concluded that the stray sands were reworked Napoleon and suggested Napoleon islands in the Michigan seas. Eddy[8] was of the same opinion regarding the gas-producing sands in the Crystal area.

In 1936 the United States Bureau of Mines published an extensive report[9] on the gas reserves in the stray sands of central Michigan, but emphasized the economic aspects of the gas sands rather than their stratigraphy.

At present there is a rather widespread conception that all Mississippian gas is limited to the stray sands of the Michigan formation, that the Marshall produces only brine, and that sand occurrence is the controlling factor in gas production.

PRESENT METHODS OF STUDY OF STRAY SANDS

As there are no outcrops of Mississippian rocks in the area studied, all information has been obtained from well samples, sample logs, and drillers' logs. However, type localities of the Michigan and Marshall formations in Arenac, Huron, and Jackson counties were examined thoroughly. The sample logs used were compiled by geologists of the Michigan Geological Survey, the Gulf Refining Company, and the Pure Oil Company. Where possible the writer examined the samples of key wells with particular reference to the Michigan and Marshall formations. Unfortunately some of the sample logs did not contain as much detailed information as desirable and could not be checked.

In some areas it was necessary to use drillers' logs. Although these were correlated with all the near-by logs available, their lack of detail and possible depth inaccuracies still remain as a potential

[5] M. D. Stearns and C. W. Cook, "A Petrographic Study of the Marshall Formation and Its Relation to the Sand of the Michigan Series Formation," *Michigan Acad. Sci., Arts, and Letters*, Papers, Vol. 16 (1932), p. 437.

[6] R. B. Newcombe, "Oil and Gas Fields of Michigan," *Michigan Geol. Survey Pub. 38*, Geol. Ser. 32 (1933), p. 55.

[7] R. B. Newcombe, "Natural Gas Fields of Michigan," Amer. Assoc. Petrol. Geol. Symposium, *Geology of Natural Gas* (1935), pp. 799–800.

[8] G. E. Eddy, "Geology of the Crystal Oil Field," *Michigan Geol. Survey Progress Rept. 1* (1936), p. 3.

[9] E. L. Rawlins and M. A. Schellhardt, "Extent and Availability of Natural Gas Reserves in Michigan 'Stray' Sandstone Horizon of Central Michigan," *U. S. Bur. Mines R. I. 3313* (1936).

source of error. Wherever possible, groups of logs (rather than individual logs) have been used as a basis of correlation. In this way, by comparing all the available information, a fairly accurate picture of the regional stratigraphic changes has been obtained.

ACKNOWLEDGMENTS

The writer wishes to thank Professors E. C. Case, T. S. Lovering, A. J. Eardley, G. M. Ehlers, and M. W. Senstius of the University of Michigan, under whose supervision this paper has been written, for helpful suggestions and criticism.

He also wishes to express his gratitude to R. A. Smith, G. E. Eddy, and Kenneth Gorton of The Michigan Geological Survey for allowing him access to the well logs in the Survey's possession and for helping him locate the available information.

Special acknowledgment is due to B. F. Hake and J. B. Maebius of the Gulf Refining Company, and Lynn Lee and C. K. Clark of the Pure Oil Company who have been extremely helpful in furnishing samples, sample logs, and formational tops.

The assistance and helpful suggestions of R. B. Newcombe and George D. Lindberg are also greatly appreciated.

REGIONAL GEOLOGY

STRATIGRAPHY

Beneath the glacial drift of the Southern Peninsula of Michigan, rocks ranging in age from the Silurian possibly to the Permian crop out in broad concentric bands. The formations dip gently toward the central part of the state and form a nearly circular geologic basin.

A generalized section of the Devonian and Mississippian strata of central Michigan has been prepared (Fig. 2). Detailed discussion, however, will be confined to the Coldwater, Marshall, and Michigan formations, as the others have no direct bearing on the problems studied. For a description of all the Paleozoic rocks in Michigan, the reader is referred to Newcombe's report.[10]

In the area studied the Coldwater formation consists of blue and gray shales with arenaceous and calcareous layers and ranges in thickness from 800 to 1,000 feet. Generally the formation is more sandy in the eastern part of the state and more calcareous in the western part. Individual arenaceous or calcareous strata are ex-

[10] R. B. Newcombe, "Oil and Gas Fields of Michigan," *Michigan Geol. Survey Pub. 38*, Geol. Ser. 32 (1933).

SYSTEM	SERIES	GROUP	FORMATION	THICKNESS AND DESCRIPTION OF FORMATIONS IN CENTRAL MICHIGAN AS INDICATED BY WELL LOGS AND SAMPLES
MISSISSIPPIAN	IOWAN	MERAMEC	BAYPORT LIMESTONE	0-100 Ft. (?) White, grey and blue fossiliferous limestone. White and grey sandstone and conglomerate. Often indistinguishable in wells from overlying Parma Sandstone.
		OSAGE OR MERAMEC OR BOTH	MICHIGAN FORMATION	250-400 Ft. Grey, green, blue and black shales. Gypsum, anhydrite, dolomite and limestone. Calcareous and dolomitic shales. Sandy shales and lenticular sands near base. Gas.
		KINDERHOOK	NAPOLEON SANDSTONE OR UPPER MARSHALL	60-120 Ft. (?) White, yellow and grey lightly cemented sandstone. Locally pink or red and difficult to distinguish from the upper part of the Lower Marshall. Gas
			LOWER MARSHALL FORMATION	60-150 Ft. (?) Red hematitic sandstones and shales. Some grey and green shales conglomerates and gritstones. Upper and lower contacts are often indefinite
			COLDWATER SHALE	800-1000 Ft. Blue, grey, greenish and dark grey shales. Sandy, calcareous and dolomitic layers
			SUNBURY SHALE	0-50 Ft. (?) Brown, black and dark grey pyritic shales.
			BEREA SANDSTONE	0-50 Ft. Fine, micaceous, grey and yellow sandstone. Local grey shales and limes Oil and gas.
			BEDFORD AND ELLSWORTH SHALES	0-? Grey, dark grey and black shales. Difficult to separate from the underlying Antrim shales.
MISSISSIPPIAN / DEVONIAN	SENECA		ANTRIM SHALE	100-450 Ft. Brown, black and dark grey bituminous shales. Local dolomitic and calcareous layers. Contact between Mississippian and Devonian is indistinguishable.
DEVONIAN	ERIAN (ER. OR ST.)	TRAVERSE	TRAVERSE LIMESTONE	300-700 Ft. Blue, grey and buff fossiliferous limestones, locally cherty and dolomitic. Shaly limestones and blue and grey calcareous shales. Oil and gas
	ERIAN		BELL SHALE	0-100 Ft. (?) blue, grey and black calcareous and fossiliferous shales.
	ULSTERIAN	DETROIT RIVER	DUNDEE LIMESTONE	50-300 Ft. Locally may be very thin or absent. Grey to buff cherty and fossiliferous limestone. Locally dolomitic. At present the most important oil producing formation in Michigan.
			DETROIT RIVER FORMATION	300-1000 Ft. (?) Dolomite, limestone, gypsum and salt. Penetrated by few wells.
			SYLVANIA SANDSTONE	100-250 Ft. (?) White quartz sand. Local dolomitic facies and layers of siliceous dolomite.

FIG. 2.—Generalized section of Devonian and Mississippian formations in central Michigan.

tensively continuous and can be correlated in well logs. In some localities appreciable amounts of organic matter are present.

The Coldwater grades upward into the basal beds of the Marshall. The contact is not definite and in some areas rhythmical deposition is apparent with alternate beds of sand and shale. Newcombe[11] states that the gradational change generally can be determined by the appearance of several varieties of mica.

The Marshall is divided into the upper Marshall or Napoleon sandstone and the lower Marshall. The basis for this division is the presence of characteristic marine fossils and the general red color of the lower Marshall, and the lack of fossils and light colors of the Napoleon sandstone. In well cuttings, the color of the material and the local presence of a shale bed between the formations are important criteria in distinguishing them. However, in the central part of the state, red sands occurring in beds apparently equivalent to the Napoleon make such a distinction difficult.

The lower Marshall formation consists of thin conglomerates, gritstones, red sandstones, and red and green shale. In the "Thumb" district a "peanut" conglomerate[12] occurs near the base of the formation. According to Newcombe[13] the red color so common in the lower Marshall of eastern Michigan is absent locally in the western part of the state. In some areas the relief of the upper surface of the lower Marshall formation implies an unconformity between it and the overlying Napoleon sandstone.[14]

Economically the Marshall formations are important for the large quantities of brine obtained from them. It is also probable that some of the Mississippian gas occurs in the upper part of the Napoleon sandstone.

The Napoleon formation is composed mostly of white and yellow sandstone. The grains are angular and vary considerably in size in different parts of the formation and in different localities. In outcrops much cross-bedding is visible. So far no fossils have been found in the Napoleon with the possible exception of bits of carbonized wood. In the central portion of the basin pink and red colors are common. Stearns and Cook[15] found no distinctive minerals or

[11] R. B. Newcombe, *op. cit.*, p. 55.

[12] A. C. Lane, "Geological Report on Huron County," *Michigan Geol. Survey*, Vol. VII (1909), p. 19.

[13] R. B. Newcombe, *op. cit.*, p. 56.

[14] *Ibid.* p. 81.

[15] M. D. Stearns and C. W. Cook, *op. cit.*, p. 437.

mineral aggregates in the lower Marshall, Napoleon, and Michigan formations. In fact, these rocks are almost barren of the detrital heavy minerals throughout their geographical extensions.[16]

Thomas[17] noted evidences of an unconformity near the top of the Napoleon sandstone in the eastern part of the state and, as previously mentioned, proposed that the term "Napoleon" be limited to the sands beneath this break, and that "Upper Marshall" be applied to the similar-appearing sandstones above. Newcombe[18] did not favor this suggestion, but believed the upper sandstone to be included in the Michigan formation. Later, in describing the Michigan stray sand,[19] he states that,

> the Michigan "sand" is somewhat lenticular and its character changes as it overlaps northwestward up the regional dip. . .The interval between the "gas" sandstone and the Marshall sandstone increases locally off structure as well as regionally. The sandstone is better developed on structure than off structure. This sand condition may have been caused by deposition concomitant with folding and by the remoteness of the structurally low places from the source of supply. The sand was distributed by currents in many places along axes of folding so that it was deposited thickest in the structural saddles. . . The physical characteristics of the "gas" sand grains are similar to the Marshall sand but the size is smaller and they show evidence of being reworked.

The writer does not entirely agree with Newcombe's conception of the stratigraphy of the stray sand and the Marshall formation. However, it seems advisable to describe the various parts of the area studied, and then combine them in an integral whole, rather than to discuss the stratigraphy at this place.

The Michigan formation is composed of gray, green, blue, and black, gypsiferous and micaceous shales. In central Michigan it varies in thickness from 250 to 400 feet. Thick beds of gypsum and anhydrite, commercially worked in some localities, occur in the lower part of the formation. Limestones and dolomites are common and lenticular sands are found near the base of the formation in some areas. The gypsum and the presence of ripple marks and diastems in outcrops of the Michigan suggest shallow-water and evaporite conditions.

In central Michigan a bed of brown crystalline dolomite is found 100–300 feet below the top of the Michigan formation. This

[16] *Ibid.*

[17] W. A. Thomas, *op. cit.*

[18] R. B. Newcombe, *op. cit.*, p. 55.

[19] R. B. Newcombe, "Natural Gas Fields of Michigan," Amer. Assoc. Petrol. Geol. Symposium, *Geology of Natural Gas* (1935), pp. 798–99.

dolomite may be distinguished in well samples from the other dolomitic beds in the Michigan section.

As far as the writer can ascertain, B. F. Hake, of the Gulf Refining Company, was the first to recognize the importance of this stratum and to suggest that it be used as a horizon marker. The writer has found the brown dolomite to be a very satisfactory marker, not only because of its wide areal extent, but also because of its thinness and uniform appearance. Moreover, it marks a change in the general type of Michigan sediments, as the sands of this formation occur almost entirely below the dolomite. This would suggest a deepening of the sea or a lessening in the amount of material that was brought in from the surrounding land masses, or a decrease in the rapidity of erosion of the adjacent land areas.

Fossils occurring in the Michigan formation are ordinarily concentrated in thin layers. The fauna consists of a group of hardy types that no doubt existed in scattered localities throughout the basin and spread rapidly whenever environmental conditions became favorable.

STRUCTURE

According to Newcombe[20] the Southern Peninsula of Michigan is,

> a major, isolated, structural and stratigraphic basin which is somewhat elongate or synclinal northwest and southeast. Structurally, it is limited by the bifurcating limbs of the Cincinnati arch on the south, the Wisconsin "island" on the west, and the Laurentian land mass or Canadian shield on the north and east. . . . The complete sedimentary sequence of rocks probably attains a total thickness in the center of the "basin" of 10,000–12,000 feet.

The central portion of this basin is crossed by a series of parallel northwest- and southeast-striking gentle folds that are separated from each other by somewhat regular intervals of about 12–15 miles. Cross-folding at approximately right angles to the main trends is apparently important in the formation of anticlinal domes and in controlling oil and gas accumulation. The local anticlinal structures are generally arcuate and asymmetric with the steepest dip on the basinward flanks. The intervening synclines are broader and more gentle. As a rule the folds are steepest in the northeastern part of the state.

The structural history of the basin is complicated, as gentle folding or warping probably occurred at intervals in all the geologic periods that are represented. It is probable that the axes of the folds

[20] *Ibid.*, p. 788.

shifted slightly from time to time but were related to zones of weakness in the underlying crystalline rocks. The fact that closures on younger formations do not directly overlie those on older formations suggests that the composite structures as they now exist are the result of deformations both during and at intervals after sedimentation.

Geology of Gas Fields

As mentioned in the introduction, the area studied is crossed by three main northwest-striking anticlines about 15 miles apart (Fig. 1 and Fig. 16). The northeastern and central folds were recognized by Newcombe in 1933 and called the "Greendale" and "Broomfield" "highs," respectively.[21] The Greendale "high" can be followed from Porter Township, Midland County, northwestward through the northeastern part of Isabella County to Grant and Surrey townships, Clare County. The Greendale, Porter, and Jasper oil fields, the Leaton and Vernon oil and gas fields, and the Clare gas field are all on this structure.

The Broomfield "high" has not been definitely outlined save in the vicinity of the Broomfield gas and oil field. This field is at present the only important producing area on the fold, although a small gas field in Elba Township, Gratiot County, may be on the southeast continuation of the Broomfield anticline.

The Austin gas field was the first important field to be discovered on the southernmost of the three folds. Accordingly, the writer proposes to call the anticline the "Austin high." The fold can be traced from Austin and Colfax townships, Mecosta County, through the northeastern part of Montcalm County to New Haven Township, Gratiot County. The Austin and Six Lakes gas fields and the Crystal-New Haven oil and gas area are on this structure.

As the main stratigraphical changes take place laterally at right angles to the folds, the fields on any one fold are stratigraphically similar. Therefore, the gas fields may be grouped for study in three groups, each corresponding with an individual fold.

GAS FIELDS ON GREENDALE "HIGH"

CLARE GAS FIELD

Location.—The Clare field is in Grant, Hatton, and Surrey townships, southern Clare County. It was the first field to produce commercial quantities of gas from Mississippian rocks and is situated on the Greendale "high" of the area discussed. So far no com-

[21] R. B. Newcombe, "Oil and Gas Fields of Michigan," *Michigan Geol. Survey Pub. 38*, Geol. Ser. 32 (1933), pp. 162–63.

mercial production has been found on this fold north of Clare field. There have not been a sufficient number of wells drilled to explore the area thoroughly, or even definitely to outline the possible extension of the structure north or northwest.

Economics.—Eight wells in the field struck commercial quantities of gas. Two reported gas showings and six were dry holes. Two other holes were drilled a few miles southeast of the field. These are structurally low, although the well in Section 18, Grant Township (Fig. 6) may be on or near the crest of the main fold at that point. Showings of heavy black oil and water in the gas sand were reported in some

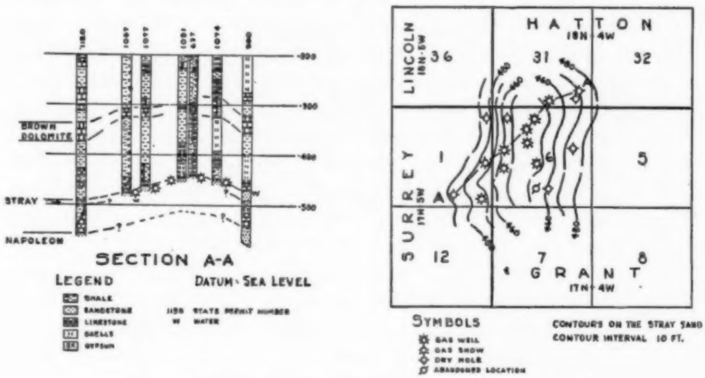


FIG. 3.—Structural map and cross section of Clare gas field.

well logs. The producing wells had an average estimated open flow of approximately 4 million cubic feet per day each, and the productive thickness of the sand was calculated to be 4.0 feet.[22] Some wells were drilled to the Dundee in search of oil, but no production was obtained.

Stratigraphy.—In the Clare gas field the Michigan formation averages about 400 feet in thickness. It consists of a series of blue, gray, and black shales, with beds of dolomite, sandy dolomite, limestone, gypsum, and anhydrite. The brown dolomite previously mentioned as a marker is found about 160 feet below the top of the Michigan and is 15–35 feet thick. About 120 feet below the brown dolomite is a gray micaceous and dolomitic sandstone which ranges from 10 to 30 feet in thickness and is the gas-producing formation. Available data indicate that the term "stray sand" was first applied to this bed.

[22] U. S. Bureau of Mines, *op. cit.*, p. 21.

Between the stray and the underlying Napoleon sandstone is an interval of 40–60 feet of dolomite, sandy dolomite, limestone, and blue, gray, or black shale. Some gypsum was reported in these strata.

Well records show 90–100 feet of Napoleon sandstone which consists of gray, white, and yellow sandstone of varying grain size. This formation is in turn underlain by the lower Marshall which contains red hematitic sandstones with some red and gray shales. It ranges from 70 to 80 feet in thickness in the Clare area.

Structure.—A contour map of the field based on the stray sand (Fig. 3) shows that the production is located on a north- and south-trending anticline that has definite east and west closure and probably has north and south closure. All commercial gas occurs above the −480-foot contour, and seems to extend farther down the west flank of the structure than on the east. The west flank of the anticline faces the center of the major basin and, therefore, has a greater gathering field than the east flank. Accordingly, porosity variations in the producing sand could logically account for the greater gas accumulation on the west flank.[23] However, possible inaccuracies in depth measurements might be sufficient to explain this.

The cross section (Fig. 3) shows the general type of sediments, the location of the important strata, and the extent of the stray sand. Although the sand varies in thickness it does not seem to be concentrated on any particular part of the structure and the gas is generally confined to the part of the bed that is structurally high.

VERNON OIL AND GAS FIELD

Location.—The Vernon field is in Vernon Township, Isabella County, about 9 miles southeast of the Clare field and on the same fold.

Economics.—Oil was discovered here in the Dundee[24] limestone in April, 1930. In October, 1930, a well in Section 26 of the Vernon Township was completed as a commercial gas producer from the stray sand. Subsequently a number of wells were drilled for both gas and oil. Eighteen wells were completed as gas wells in the stray and 11 others that were drilled to the Dundee limestone reported commercial gas volumes in the stray sand. The average initial open flow of the gas wells was about 1,600,000 cubic feet per day each, and the productive thickness of the sand approximately 2.1 feet.[25]

[23] W. H. Emmons, *Geology of Petroleum* (1931), pp. 99–100.

[24] As yet it has not been satisfactorily determined whether the oil-producing rocks at Vernon belong to the Dundee or to an older formation.

[25] U. S. Bureau of Mines, *op. cit.*, p. 21.

As in the Clare field, showings of heavy oil and water were reported in the producing sand. Some well logs, moreover, mention gas showings in the top of the Napoleon sandstone.

Stratigraphy.—Well logs in the Vernon area are in general very poor. Only a few sample logs are available, and the drillers' logs as a rule contain little information. Many of the wells were drilled for oil, and no attention was given the upper formations. It was not uncommon for drillers to pick the first sand they struck in the Michigan formation and to call this the top of the Napoleon, overlooking the intervening limestones and shales. It was necessary, therefore, to make strip logs of practically all the wells in the field in order to obtain accurate Napoleon tops. Even so, many logs could not be used because of their lack of detail, and some of the tops are questionable.

The few sample logs available record a section from the Bayport to the Coldwater that is much the same as the section in the Clare area. The intervals between the various markers are slightly different and some of the formations differ in thickness from the Clare section previously described. However, the general type of sediments is the same, and the variations are not sufficient to necessitate repeating the section in detail.

The brown dolomite occurs about 200 feet below the top of the Michigan formation and the stray is found approximately 150 feet below the top of the dolomite and 30–50 feet above the Napoleon. The Napoleon and lower Marshall formations are generally thicker but otherwise similar to their counterparts in the Clare area. Graphic logs of Vernon correlate very well with similar logs of the Clare field, and the gas-producing sand of the two areas is apparently the same.

Some logs report two or more sand layers in the general stray zone, and it is apparent that the stray is more lenticular in the Vernon area than in the Clare area. Sand lenses also appear in the Michigan formation somewhat higher stratigraphically than the producing stratum. So far no gas has been recorded in any of the upper sand lenses in this area, although they indicate other sandy zones in the Michigan that are similar to the main stray sand. These zones occur at varying intervals between the stray and the brown dolomite.

Many well records show black shales in the lower part of the Michigan formation in some places in contact with the stray. It is possible that these may be source beds of some of the gas.

Structure.—The structural map (Fig. 4) of the Vernon field is contoured on the Napoleon sandstone. This is a more satisfactory

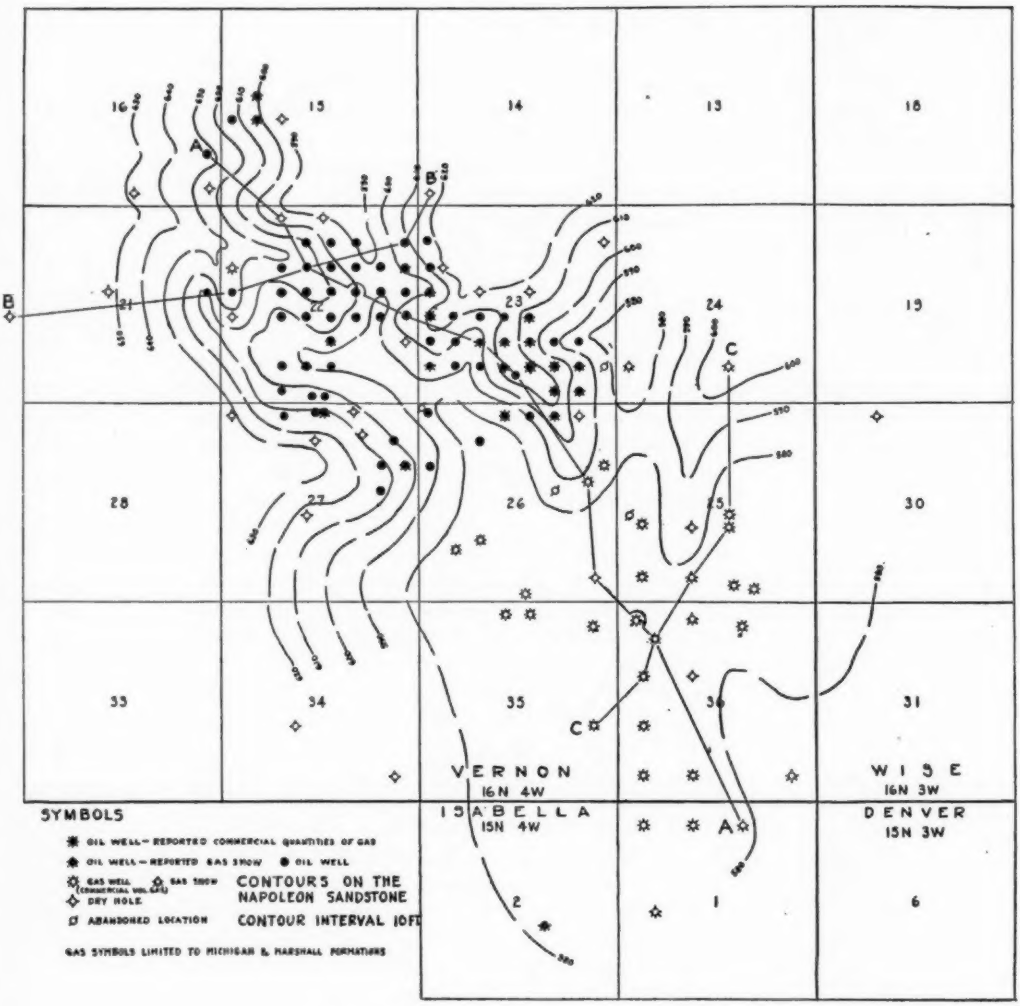


FIG. 4.—Structural map of Vernon oil and gas field.

marker than the stray, for in the north end of the field the lenticular character of the sand and the poor logs available do not portray the true structural conditions. In the gas-producing area, the interval between the stray and the Napoleon does not vary sufficiently to appreciably change the reflection of the underlying structure.

The contour map suggests a northwestward-striking anticline which is cross folded in the area of gas production. The result is a broad flat dome in the southeast portion of the field. It is noteworthy that the gas is generally located over the highest area of the Napoleon sandstone, although a few wells (in Section 23 of Vernon Township) showing commercial volumes of gas are definitely off structure. This may be due to a variation in the sand porosity and in the thickness of the "stray to Napoleon interval." It is also possible that the drillers overestimated gas volumes, and that these wells should only be recorded as having had gas showings.

The regional map (Fig. 6) shows that the cross fold extends at least 10 miles east and west. A few small gas wells in Section 31, Vernon Township, are apparently on this fold about 4 miles west of the main gas-producing area. The local structure seems to be a small dome in the regional syncline, and the gas is found in sands that correlate with the stray in the Vernon field. The record of a well in Section 10, Wise Township, about 4 miles northeast of the main gas area, indicates that a large showing of gas was found in a sandy stratum equivalent to the stray. This well seems to be located on the eastward extension of the cross fold. In general, however, the sand content of the Michigan formation decreases east of the Vernon field, and the stray thins to the vanishing point within a few miles.

The cross sections (Fig. 5) show the wide areal extent of the stray sand in the field and the definite relation between gas occurrence and the high areas of the sand. There does not seem to be any sand concentration on the flanks of the Marshall and Michigan structure, although the lenticular nature and the variations in the thickness of the stray are obvious.

Relation between Marshall and Dundee structures.—As indicated in Figure 4 and Figure 5, the Marshall and Michigan formations are structurally higher in the area of gas production southeast of the Dundee oil-producing portion of the field. An examination of the well records reveals that the Dundee is generally higher in the northwest portion. This difference is explained by a variation in the thickness of the "Marshall to Dundee interval" which reaches a minimum in the oil-producing area (Fig. 7).

As the formations of the Marshall group are generally consistent

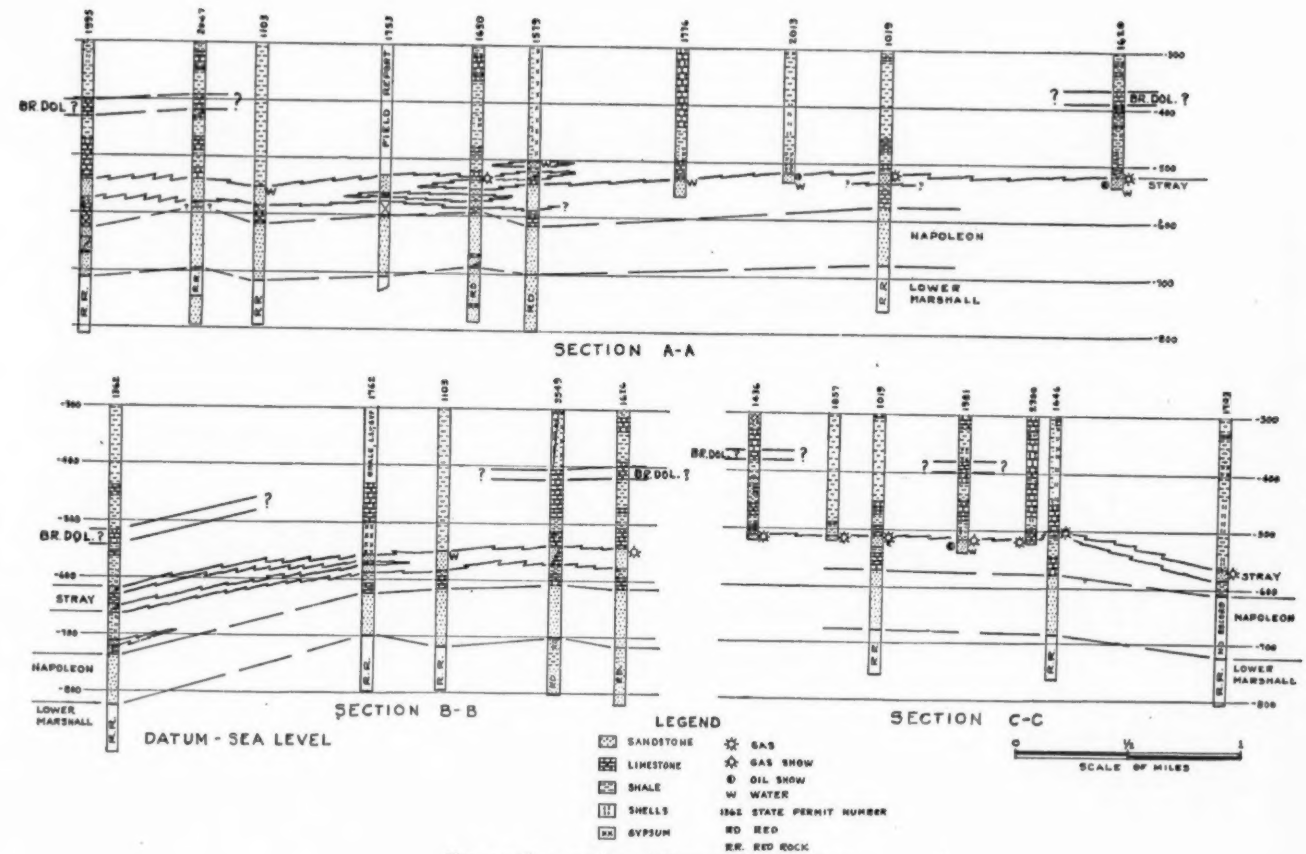


FIG. 5.—Cross sections of Vernon oil and gas field.

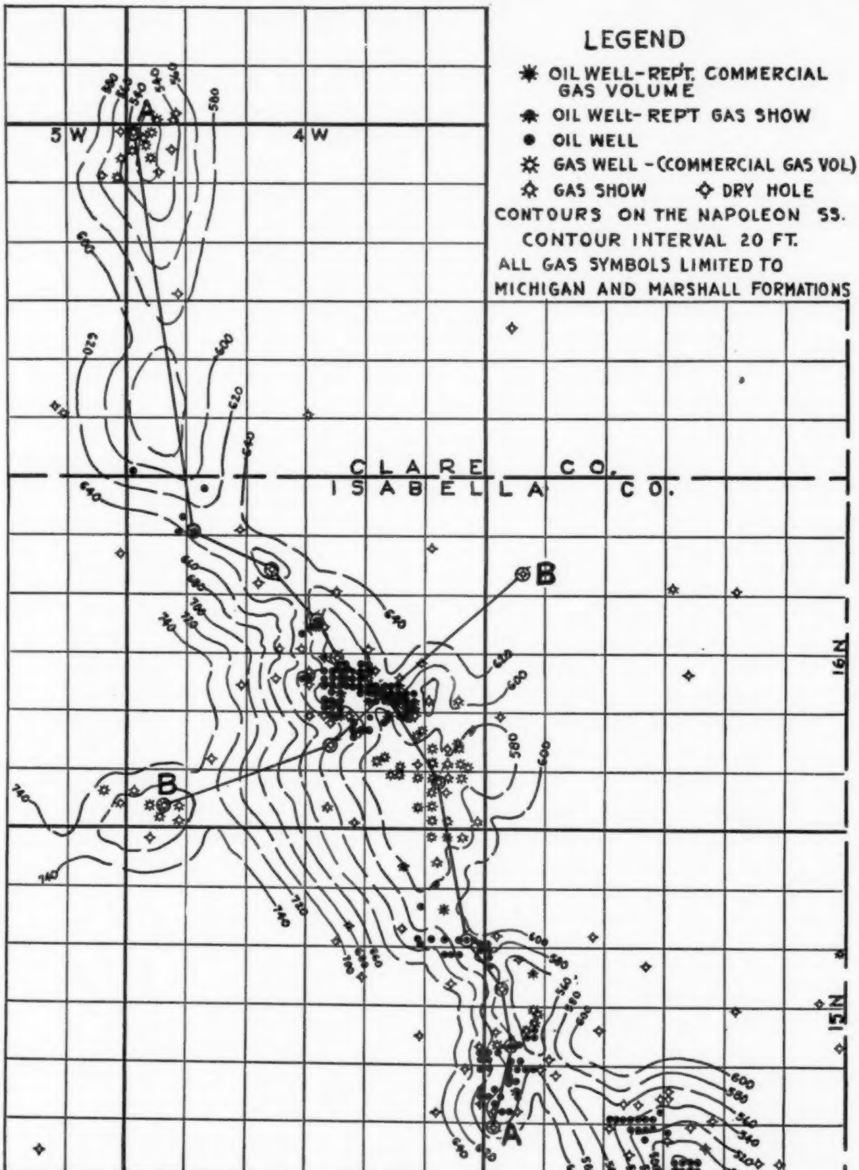


FIG. 6.—Structural map of Clare-Vernon-Leaton area.

in appearance and thickness throughout the entire area, it may be assumed that they were deposited on a comparatively flat surface. If so, the variation in the thickness of the "Marshall to Dundee interval" might conceivably be due to pre-Marshall structure that has been covered over and flattened out by the thick series of shales and limestones that occur between the Dundee and the Marshall.

The fact that the interval between the Marshall and Dundee formations in the oil-producing area has a minimum thickness suggests that pre-Marshall structure is locally a controlling factor in oil accumulation. Other factors, such as porosity variations in the limestone and the present closures on the Dundee, may be equally or more important, and are difficult to appraise.

LEATON OIL AND GAS FIELD

Location.—The Leaton oil and gas field was discovered in September, 1929, in Denver and Isabella townships, Isabella County, about 4 miles southeast of the Vernon field on the same major fold (Fig. 6). Oil is found in the Dundee limestone, and a few wells northeast of the main oil-producing area struck commercial quantities of gas in the Michigan stray. The gas production is of minor importance, but the field is geologically interesting since the relation between the Marshall and Dundee structures is similar to that of the Vernon field. As in Vernon the gas occurs above a Marshall "high," gas production is not superposed over oil production, and the "Marshall to Dundee interval" has a minimum thickness in the oil-producing area.

Stratigraphy.—The Marshall and Michigan formations are similar to their equivalents in the Clare and Vernon areas. The stray sand is apparently the same as the gas-producing horizon in the Vernon and Clare fields, but varies more in its vertical locations in the stratigraphic column. Some wells in the Leaton area show an interval of 60 feet between the stray and the Napoleon. In others the interval is only 20 feet. Higher sand lenses occur as in the Vernon field. A contour map on the stray sand, therefore, would not portray accurately the underlying Napoleon structure. A regional map of the area (Fig. 6), however, shows that the gas production is generally found over the high Napoleon areas in the Vernon field.

East and northeast of the main fold in the Leaton area, the Michigan formation becomes less sandy, and the Marshall group thins. The stray sand grades laterally into shales and limestones or dolomites, and disappears.

Well logs in the Leaton area are poor. Few could be used for

correlations with any degree of accuracy. No samples or sample logs were obtained from wells in the Leaton area proper, but cuttings had been saved and were examined from a well about 2 miles farther east in Section 27, Denver Township.

Structure.—The structure appears to be similar to that of the Vernon field. The main anticline is cross-folded to produce a sharp dome. The Marshall "high" is not directly over the Dundee "high" and, as in the Vernon field, oil and gas production are not superposed. Well records reveal again a minimum "Marshall to Dundee interval" over the oil-producing area of the field (Fig. 7).

No commercial quantities of gas have been found in Mississippian rocks southeast of the Leaton area on the Greendale "high," although there are a number of large Dundee oil fields. The main structural trend continues for some distance and underlies the Greendale, Porter, and Jasper oil fields. Well records in these fields show the presence of the stray and other sandy horizons in the Michigan formation below the brown dolomite, and some logs suggest a very sandy lower Michigan section. However, only gas showings have been reported. This may be due to poor source bed conditions or to lack of closure on the stray sand, although the former seems a more plausible suggestion.

In general the Michigan formation in this area is more sandy on structure than off structure, and the stray sand may be followed in well logs at least to the southeastern end of Porter Township, Midland County (Fig. 7 and Fig. 17), although the lack of detail in the logs makes correlations very difficult.

GENERAL RELATION OF CLARE, VERNON, AND LEATON FIELDS

A compilation of the data indicates that the Michigan and Marshall formations are fairly uniform and persistent in the fields on the Greendale "high." This relationship extends from the Clare gas field through the Vernon and Leaton fields, at least to Porter Township in Midland County, a distance of approximately 35 miles. Well records show that the Michigan formation is generally more sandy on structure than off structure, but that regionally it becomes more sandy south and southeast. East of the main fold, with local variations, the sand content of the Michigan grows generally less, and the Napoleon and lower Marshall formations thin, suggesting offshore conditions.

As far as can be ascertained, the producing horizon or stray sand is the same stratigraphically in the Clare, Vernon, and Leaton areas, and this generally sandy facies of the Michigan formation may be

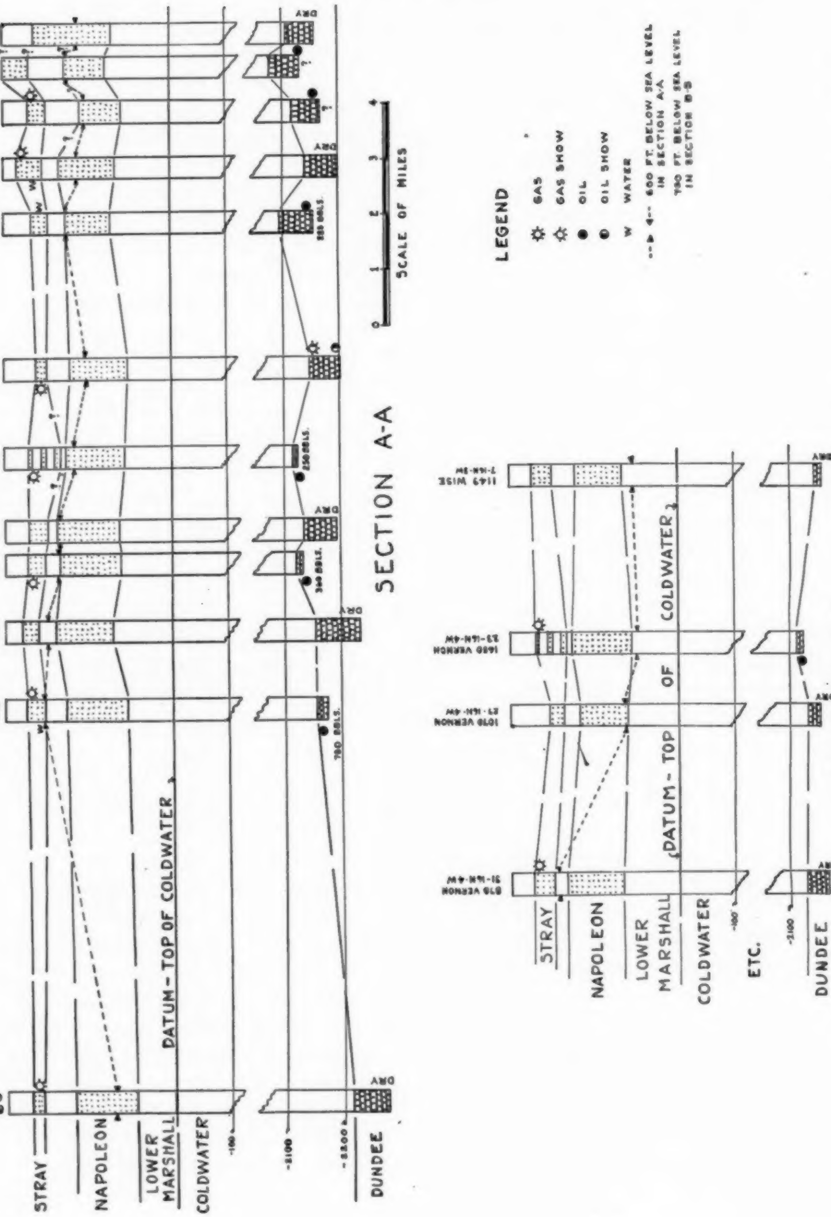


FIG. 7.—Generalized cross sections of Clare-Vernon-Leaton area showing thinning of "Marshall to Dundee interval" in areas of oil production. The word "DRY" at the base of several sections merely indicates no oil found.

followed for some distance southeast of the Leaton field, although other sands occur stratigraphically higher in the Michigan formation.

The field maps indicate that the gas production is limited to the stray sand horizon, although showings of gas have been reported in the Napoleon sandstone. In this area the stray is separated from the Napoleon by an interval of 20–50 feet of dolomite, sandy dolomite, limestone, and shale. These beds are probably at least in part equivalent to the strata that Thomas noted as an indication of an unconformity in what he considered to be the upper part of the Marshall group.[26]

The stray is widespread throughout the area and shows little evidence of local concentration. Gas production, therefore, seems to be controlled more by the structural position of the sand than by sand occurrence, although the presence of a reservoir bed is obviously a basic necessity.

The gas areas are not superposed over the areas of Dundee oil production, due to a variation in the thickness of the interval between the stray and the Dundee limestone. The cross sections of the northeast area in Figure 7 show this relationship. The sections are based on the top of the Coldwater as a datum plane, since this horizon may be located in poor well logs with more accuracy than the top of the Napoleon, stray, or brown dolomite. Even so, as the Coldwater and Marshall contact is gradational and the well logs generally deficient in detail, accurate results are not possible. Nevertheless, the evidence is sufficient to be convincing, especially as similar conditions are present throughout the oil-producing areas of the Crystal and Broomfield fields. Moreover, sections across the Clare and Six Lakes gas fields show no definite variations in the "Marshall to Dundee" or "brown dolomite to Dundee interval," and as yet no oil production has been obtained from the Dundee in these areas.

Structurally the fields are located on a main northwest-striking fold known as the Greendale "high," that turns in a more northerly direction in the Clare area. The fields are situated at intervals along this fold, and in the Vernon and Leaton areas, cross-folding seems to be an important factor in controlling the gas production. The contour map (Fig. 6) shows that in the southeastern part of the area the axis of the main structure dips toward the northwest, reaches a maximum depth and flattens out in the vicinity of the Vernon field, and begins rising again in the Clare area.

[26] W. A. Thomas, *op. cit.*

GAS FIELDS ON BROOMFIELD "HIGH"

BROOMFIELD OIL AND GAS FIELD

Location.—So far only one important field has been discovered on the Broomfield "high." This, the Broomfield oil and gas field, is in northern Broomfield and southern Sherman townships, Isabella County, about 15 miles southeast of the Vernon field (Fig. 1 and Fig. 16).

Economics.—Gas was discovered in February, 1930, but no oil was found until October, 1936, when a well in the southwest quarter of Section 34, Sherman Township, encountered commercial quantities of oil in the Dundee (?) limestone. At present there are 15 oil-producing wells located on the northern edge of the main gas area, and others are being drilled.

Available records show that 90 wells have been drilled in the Broomfield area. Of these 57 were completed as gas wells or reported commercial quantities of gas in Mississippian rocks, 17 cut showings of gas, and 10 were dry holes.

The average initial open flow of the gas wells was about 2,400,000 cubic feet per day per well, and the average productive thickness of the sand is calculated to be 3.2 feet.[27] Water in or near the producing horizons was reported in some wells. The gas occurs in two or more sandy zones at the base of the Michigan formation approximately 1,300 feet below the surface.

Stratigraphy.—With the exception of the more recent wells, available well logs in the Broomfield area are generally deficient in detail. Many drillers recorded large sections of the Michigan formation as "shale and shells" or used similar undescriptive terms. It is also probable that certain beds of gypsum were erroneously termed "lime." The writer was able to obtain sample logs from only three wells in the field outside of the oil-producing area and in two of these the samples began below the brown dolomite.

The Michigan formation in the Broomfield field is about 350 feet thick. As in the Clare and Vernon areas, it is composed of gray, green, and black, gypsiferous and micaceous shale. Beds of limestone and dolomite are not uncommon, although the formation seems to be less calcareous at Broomfield than farther east and northeast.

Two thick beds of gypsum occur in the central part of the Michigan formation. These are apparently of wide areal extent, as they have been recognized in many wells in adjacent townships. The brown dolomite is found just below the gypsum approximately 220 feet above the Marshall.

[27] U. S. Bureau of Mines, *op. cit.*, p. 27.

The section below the dolomite becomes more sandy, and at the base of the Michigan formation two or more sandy zones are present. These sand lenses are usually termed the stray sands, for they appear to be the gas reservoirs in this field.

The contact between the Michigan and Marshall formations is poorly defined in this area, and the relation between the gas-producing sands and the Napoleon sandstone is obscure. Characteristically the well records term the gas-bearing horizons stray sand, while the term "Napoleon" is limited to the strata containing brine.

In samples the gas sands are similar to the producing sands of the Clare and Vernon fields. They are gray, dirty, and partially cemented with calcareous or dolomitic cement. The dirty appearance seems to be due to a gray kaolin-like substance present in places, the cementing material, and possibly a very small amount of carbonaceous matter. The salt-water sands, on the other hand, are generally clean, light-colored, and comparatively uncemented.

This distinction is not definite, because many unproductive wells record gray sands in the upper part of the Marshall which are difficult, if not impossible, to distinguish from the gas sands.

In some places thin beds of shale, gypsum, or dolomite are found between the gas sands and the underlying brine-bearing horizons. In other localities, no intervening layers are present, but a tight zone occurs. These criteria have commonly been used to separate the stray sands from the Napoleon sandstone. The writer does not believe that such distinctions are sufficient to warrant a definite separation. However, similar conditions exist in other fields and the matter will be subsequently discussed in more detail.

In the Broomfield area the Marshall section is approximately 280 feet thick. The upper 200 feet consist of white and yellowish sandstone, ranging from fine to coarse in texture. Two or more zones of reddish sand occur at varying intervals within this section. The lower 80 feet or so is composed of a series of red, hematitic sands and shales, similar to the lower Marshall in the Clare and Vernon areas. Below the red sands 20 or 30 feet of light-colored dolomitic shales and sands appear that suggest a gradational contact between the Marshall and the underlying Coldwater formation. The exact boundaries of the Napoleon sandstone and lower Marshall formation are difficult to determine because of the red sands in the upper part of the section, and the gradational contact at the top of the Coldwater. However, well-log correlations suggest that the lower and hematitic part of the section is equivalent to the lower Marshall formation in the Clare and Vernon areas.

Structure.—Due to the poor well logs and the lenticular sand conditions, it is impossible to correlate an individual bed in the Michigan or Marshall formations throughout the area, or to obtain a satisfactory contour horizon. The contour map (Fig. 8) is based on the pay sands or gas-bearing strata recorded in the well logs. However, as it seems probable that gas occurs in two or more stratigraphically distinct sands, the locations of the contours are only approximate and the map merely suggests the general structure. The field is somewhat similar in appearance to the Vernon gas field (Fig. 5). The

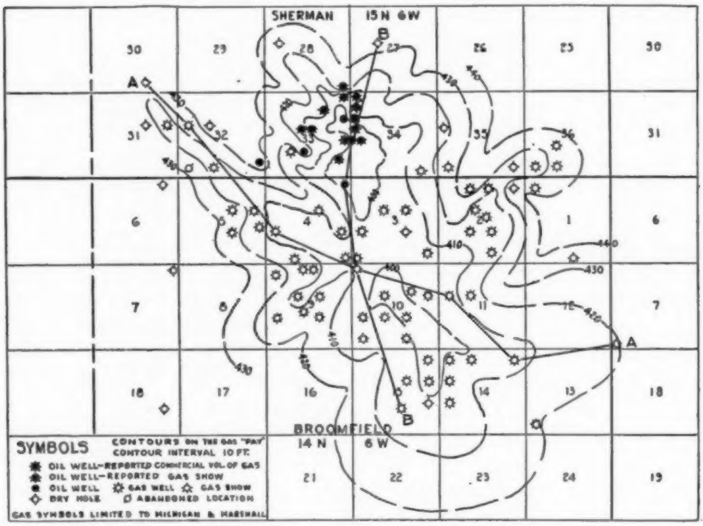


FIG. 8.—Contour map showing subsea elevation of gas "pay" in Broomfield oil and gas area.

production is located on a northwest-striking anticline that appears to be cross-folded in the central part of the area. Subsea elevations of the reported Napoleon tops are generally in accordance with the structure as outlined, but there are some definite exceptions.

It should be noted that the elevations of the "pay" are lowest on the northeast or basinward flank of the structure. As previously mentioned, this condition occurs in the Clare gas field. It is also present in the Austin and Six Lakes fields and may be due to greater gas accumulation on the basinward side of the structure caused by variations in sand porosity.

The cross sections (Fig. 9) show the lenticular nature of the sand and suggest the structure as indicated by the elevations of the "pay," although correlations are very doubtful.

On the whole, the logs of the Broomfield area are so poor, and the information available so lacking in detail, that only a very inaccurate picture of the structure and stratigraphy can be obtained.

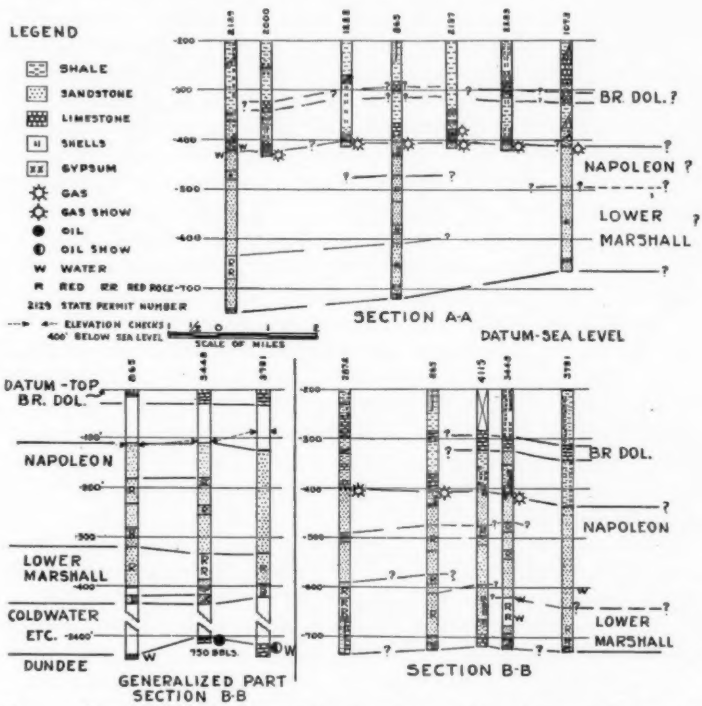


FIG. 9.—Cross sections of Broomfield oil and gas field and generalized section showing thinning of "brown dolomite to Dundee interval" in area of oil production.

Relation between Marshall and Dundee structure.—A generalized part of section BB has been constructed (Fig. 9), and deepened to include the Dundee, using the top of the brown dolomite as a datum plane because the top of the Coldwater is too indefinite in this area. As in the Clare-Vernon-Leaton area, a distinct thinning of the section occurs over the area of oil production, suggesting that pre-Marshall, or in this case, pre-brown dolomite structure is an important factor in oil accumulation.

GAS FIELDS ON AUSTIN "HIGH"

CRYSTAL-NEW HAVEN OIL AND GAS AREA

Location.—The Crystal-New Haven oil and gas area is the southernmost of the producing areas on the Austin "high." It may be subdivided into the Crystal oil and gas field and the New Haven gas field. As both fields are stratigraphically similar and within a few miles of each other, they will be discussed together.

The Crystal field is in northern Crystal and southern Ferris townships, Montcalm County, and the New Haven field in northern New Haven and southern Sumner townships, Gratiot County.

Economics.—The Crystal oil and gas field was discovered in March, 1935, and is primarily an oil field producing from the Dundee limestone. Many wells, however, have reported commercial quantities of gas in the lower Michigan or the upper Marshall formation, and a few wells were drilled on the edge of the oil-producing area solely for gas production. The New Haven field was discovered in January, 1936, and at present produces only gas.

As most of the wells in the Crystal field were drilled for Dundee oil, and as the New Haven gas field is still in the developmental stage, accurate estimates of the gas production and productive sand thicknesses are difficult to determine. However, by February, 1936, 35 wells in the Crystal field had reported estimated initial open flows ranging from 500,000 to 10,300,000 cubic feet per day each.[28] Since then, the completion of other wells has added materially to the potential production.

To date, information is available regarding 39 gas-producing wells in the New Haven field. Some of these had estimated open flows of 30 million cubic feet per day, but the average is about 8 million. The field has not yet been definitely outlined, and additional drilling will undoubtedly increase the production.

Stratigraphy.—In the Crystal oil and gas area the Michigan formation is approximately 300 feet thick, and does not vary substantially from the previous descriptions. The brown dolomite occurs about 200 feet below the top of the formation and ranges from 10 to 30 feet in thickness. Bedded gypsum is present in many places above the dolomite.

Below the brown dolomite the section grows very sandy, and individual layers are so lenticular that detailed correlation is practically impossible with the available information. In this area the contact between the Michigan and the underlying Napoleon sandstone

[28] U. S. Bureau of Mines, *op. cit.*, p. 55.

is indefinite. As in the Broomfield area, the strata generally change from gray cemented sandstones above to light-colored comparatively uncemented sands below. The presence of thin shale "breaks" and beds of sandy dolomite among the upper sands are considered to be indicative of the Michigan formation. In some places, however, these shales are absent near the Michigan and Napoleon contact, but a tight zone may occur between the gas-producing sands and the underlying brine-bearing horizons.

In the Crystal field some well logs record gas in what is considered to be the Napoleon sandstone. In other wells, the gas occurs in higher sands ranging from a few feet to 60 or 70 feet above the reported top of the Napoleon.

In the New Haven field similar sand conditions are present, although the gas sand seems to be limited to a narrower vertical section and generally occurs within 30 or 40 feet from the reported top of the Napoleon. Most of the well records show thin black shales closely associated with the gas sands, and generally a shale break or thin dolomite occurs between the gas-producing horizons and an underlying, brine-bearing sand that is considered to be the Napoleon sandstone. As in other fields, however, some logs do not record this bed, and the two types of sand are in direct contact.

Available information indicates that the lower part of the Michigan formation is generally more shaly on the edges of the fields. This may be due to lack of detail in the well records, but a relation between sand deposition and structure is suggested. In this particular region sand deposition in early Michigan time may have been limited to areas of shallow water which generally correspond in location with the present structural "highs."

In the Crystal and New Haven area, the Marshall section ranges from 130 to 270 feet in thickness. The section is thickest in the eastern part of the area, and thins toward the west and southwest. Pink and red sands locally occur in the upper part of the section and some light-colored sands are present in the lower part. Accordingly, as at Broomfield, the separation of the Napoleon and lower Marshall formations is difficult. Beds of shale which separate the Marshall into two or more members are also locally present.

In general, the upper 70–100 feet of the Marshall section in this area is light-colored, whereas the lower part is red. This color change, although not a sufficient criterion to definitely delineate the Napoleon and lower Marshall formations, occurs in many parts of the area. It suggests a general depositional change. Therefore we may consider that the upper and light-colored sands are probably comparable

with at least part of the Napoleon sandstone elsewhere, and that part of the lower red sands are similarly equivalent to the lower Marshall formation in other localities. Graphic-log correlations support this observation. As in other areas, light-colored sands and shale at the base of the Marshall imply a gradational contact with the underlying Coldwater.

The cross sections (Fig. 11) and the regional stereographic diagram (Fig. 17) show the regional thinning of the Marshall west of the New Haven field. From further observation it appears that the thinning takes place in the lower and red part of the section, whereas the upper light-colored sands remain comparatively consistent in thickness throughout the area. Newcombe[29] suggested a lower Marshall overlap to the west to explain this or a similar condition.

Structure.—The structural map of the Crystal oil and gas area (Fig. 10) is contoured on the reported top of the Napoleon sandstone. As in other fields, poor logs and an indefinite contact make the contours only approximate. In addition, few wells in the New Haven field are deep enough to penetrate undoubted Marshall and give accurate control in this part of the area. However, there seems to be a general resemblance between this map and a structural map of the Crystal field contoured on the top of the Dundee.[30]

Structurally this area seems to have two or more closely associated northwest-striking folds, which have been cross-folded in an easterly direction, and perhaps in a northeasterly direction. The intersection of these folds has formed a number of domes on which the fields are located. It is noteworthy that gas production also generally occurs where the Napoleon sandstone is the highest.

The cross sections (Fig. 11) show the relation between the gas production and the subsea elevation of the sands. They also suggest that the lower part of the Michigan formation is sandier on structure than off structure.

Relation between Marshall and Dundee structure.—If either cross section is deepened to include the Dundee limestone and enlarged to include other wells and give a more detailed picture, the "Dundee to brown dolomite interval" is found to be thinnest over the oil-producing part of the area. This thinning is intensified if the Marshall and Coldwater contact is used as a datum plane rather than the brown dolomite. For either, interval conditions are similar to those in the fields on the Broomfield and Greendale "highs," and the theory

[29] R. B. Newcombe, *op. cit.*, p. 81, and Fig. 17, p. 82.

[30] G. E. Eddy, *op. cit.*, map opposite p. 7.

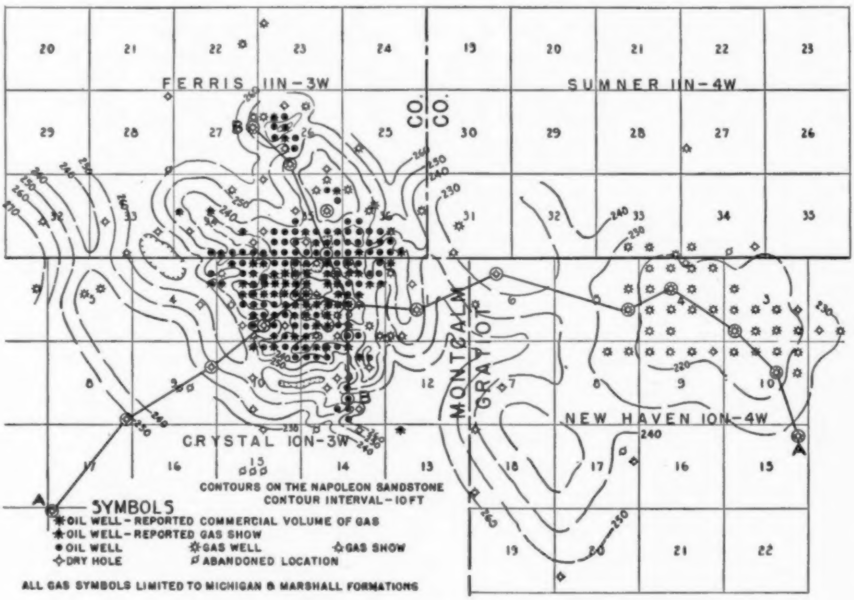


FIG. 10.—Structural map of Crystal-New Haven oil and gas area.

is strengthened that oil production is influenced by pre-Marshall structure.

SIX LAKES GAS FIELD

Location.—The Six Lakes gas field is in northern Belvidere Township, Montcalm County, and southern Hinton and Millbrook townships, Mecosta County. It is on the Austin "high" approximately midway between the Austin gas field and the Crystal-New Haven oil and gas area (Fig. 1 and Fig. 16).

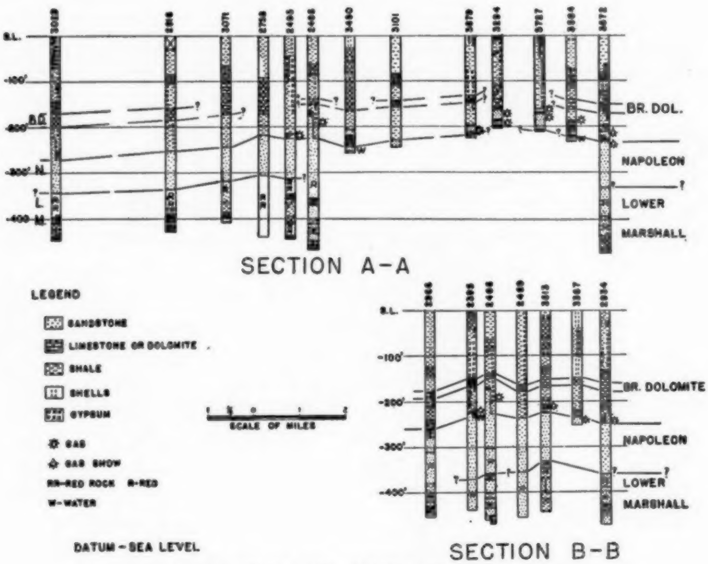


FIG. 11.—Cross sections of Crystal-New Haven oil and gas area.

Economics.—The Six Lakes field is at present the largest gas field in the state of Michigan. At the date of writing, about 215 wells have been completed as gas producers, 3 wells reported showings of gas, and 10 were dry holes. Some of the producing wells have had estimated open flows of 60 million cubic feet or more per day each, but the average is about 10 million cubic feet. In 1936 the average productive thickness of the gas sand was calculated to be 10.3 feet.[31] However, as only 75 producing wells had been completed at that time, this figure probably needs some revision. Water was reported in some edge wells in or near the producing horizon. A few wells

[31] U. S. Bureau of Mines, *op. cit.*, p. 43.

were drilled to the Dundee limestone, but no oil was found. The gas occurs in the base of the Michigan formation or the top of the Marshall formation or both, at depths of 1,200–1,300 feet below the surface.

Stratigraphy.—The Michigan formation in the Six Lakes gas field ranges from approximately 300 to 350 feet in thickness and is thinnest in the eastern and northeastern parts of the field. The upper 100 feet or so of the Michigan consists of gray and blue shales with some thin beds of gypsum, limestone, and dolomite. The remaining 200 feet contains many fairly thick beds of dolomite and gypsum.

The brown dolomite is found about 260 feet below the top of the Michigan formation and is about 30 feet thick. Below the dolomite are 60–70 feet of gray shales and thin beds of gypsum with a few thin lenticular sands. At the base of these strata the section becomes abruptly sandy with gas in the upper part of the sand. The exact contact between the Michigan and Marshall is difficult to determine if it is assumed that the upper part of the sand body is of Michigan age.

In the well records, here as in other areas, the gas-producing sand is called stray sand and the term "Napoleon" is generally limited to the brine-bearing part of the section. As in other localities the gas sands are generally gray and partly cemented with dolomitic cement, whereas the brine-bearing sands are cleaner, white or pinkish, and comparatively uncemented. Shale breaks and beds of dolomite or dolomitic sandstone occur in the upper sands in some parts of the area, and a tight zone is often found between the producing sands and the water-bearing horizons.

Graphic-log correlations based on the brown dolomite (Fig. 13) seem to show that the top of the producing sand correlates very well with the top of the Napoleon in the dry holes on the edge of the field. Moreover, some well records show red sands and shales in the productive part of the section, and this coloration is characteristic of the Marshall formations. There is no reason apparently why red beds should not occur in the Michigan formation. In fact, one driller's log in the Greendale area reports strata of this type near the base of the Michigan, and a sample log in the Austin fields records a bed of red shale about 200 feet above the Napoleon. In addition, Newcombe[32] mentions the local occurrence of red sandstones and shales in the Michigan formation.

Nevertheless, with the exception of the two logs mentioned here, the writer has seen no record of any red strata in the Michigan for-

[32] R. B. Newcombe, *op. cit.*, p. 57.

mation in the area studied. As this type of coloration is common in the Marshall, it would suggest that at least some of the producing sands in the Six Lakes field are of Marshall age.

The structural map of the field (Fig. 12), contoured on the top of the producing sand, implies sand deposition in the form of bars more or less parallel with the structural trend. This has been considered an indication that the sands of the lower part of the Michigan formation were deposited on top of the Napoleon in shallow areas of the Michigan sea. Such an assumption infers a "break," diastem, or unconformity between the Marshall and Michigan formations in the area.

The top of the water-bearing horizon across the structural "high" in the Six Lakes field is nearly level. Above the water is a tight sand, also nearly level across the "high." Gas occurs in the sand lens above the tight layer. The gas sand lens in cross section is, therefore, convex upward. In reality it is a horizontal slice off the top of the gently arched Napoleon sandstone. However, the tight sand has been considered, by some geologists, to mark the boundary between the Napoleon and Michigan formations. Certain thin shales and dolomitic beds are found locally in and at the base of the gas sand and these, too, have strengthened the supposition that the tight sand is the bottom of the Michigan. If the structural "high" is viewed in cross sections from one flank well out to the other, the gas sand lens is clearly seen as part of the Napoleon. The most plausible origin of the tight zone, considering its relation to gas, water, and structure, is a secondary one. It must have formed sometime after deposition of the sand formation, possibly even later than gas accumulation.

It seems quite possible that the upper sands of the Marshall could have been reworked in place by waves and currents. This would account for the apparent bar formation on the sands without necessitating an erosional or depositional break between the Michigan and Marshall formations.

The evidence listed by Thomas[33] to indicate an unconformity between the stray sand and the top of the Napoleon was obtained in the eastern part of the state and referred to the section on and east of the Greendale "high." The stereographic diagram (Fig. 17) shows that the stray sand and the Napoleon sandstone in this area are stratigraphically lower in the section than their counterparts in the Six Lakes field. Hence, this evidence can not be used with reference to the sand in the Six Lakes area.

The writer, therefore, although willing to concede that there is

[33] W. A. Thomas, *op. cit.*

generally a change in appearance between the gas sands and the water-bearing sands below, does not believe that the available evidence is sufficient to indicate a definite "break" between the Michigan and Marshall formations in the Six Lakes field. In addition, the well-log correlations and the comparatively uniform level of the water seem to show that the top of the producing sand is equivalent to the top of the Napoleon sandstone in the edge wells, and accordingly, some or all of the gas sands should be included in the upper part of the Marshall formation.

Since few samples of the gas sand are available, due to high gas pressure, further profitable discussion must await new drilling which, it is hoped, will add illuminating information to this difficult subject.

The deep tests in the field show that the Marshall section is similar to that described in the Crystal area. The contact between the Napoleon and lower Marshall formation is obscure because of red sand locally present in the upper part of the Marshall section. Some wells record a thick bed of blue or gray shale approximately in the center of the section which divides the Marshall into two distinct members. However, these members can not be definitely correlated with the Napoleon and lower Marshall formations elsewhere.

As indicated in the cross sections (Fig. 13), the Marshall thins westward across the field and the Michigan formation thickens. This relationship is similar to that described in the Crystal area, and probably indicates the same origin.

Structure.—The structural map (Fig. 12)[34] is based on the top of the producing sand, and probably indicates not only the general structure of the sand, but also the smaller sedimentary irregularities of the upper surface.

Structurally, the Six Lakes field seems to be located on a northwest-trending anticline which is steepest in the northwest part of the fold. There are no direct evidences of cross-folding, although the widening of the producing area in the central and southeastern parts of the field suggests a gentle cross-arching in the area. Moreover, the field regionally lines up with a southwest extension of the cross fold in the Broomfield area, which in turn may continue northeast to the Clare or Vernon fields (Fig. 16).

The cross sections (Fig. 13) show the relationship between gas production and structure, and the probable correlation between the gas sands on top of the fold and the Napoleon in the edge wells.

[34] A well in Section 31, Millbrook Township, seems to be very low. The elevation and depths on the log have been checked against the records of the State Survey, and found to be correct. Even so, it appears that this abnormality is probably due to an inaccurate well log rather than to an extremely low area in the field.

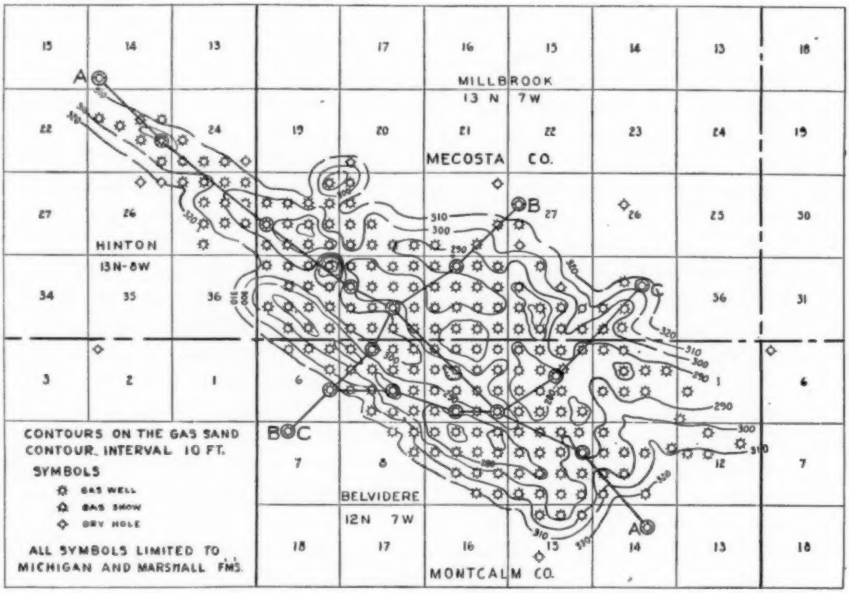


FIG. 12.—Structural map of Six Lakes gas field.

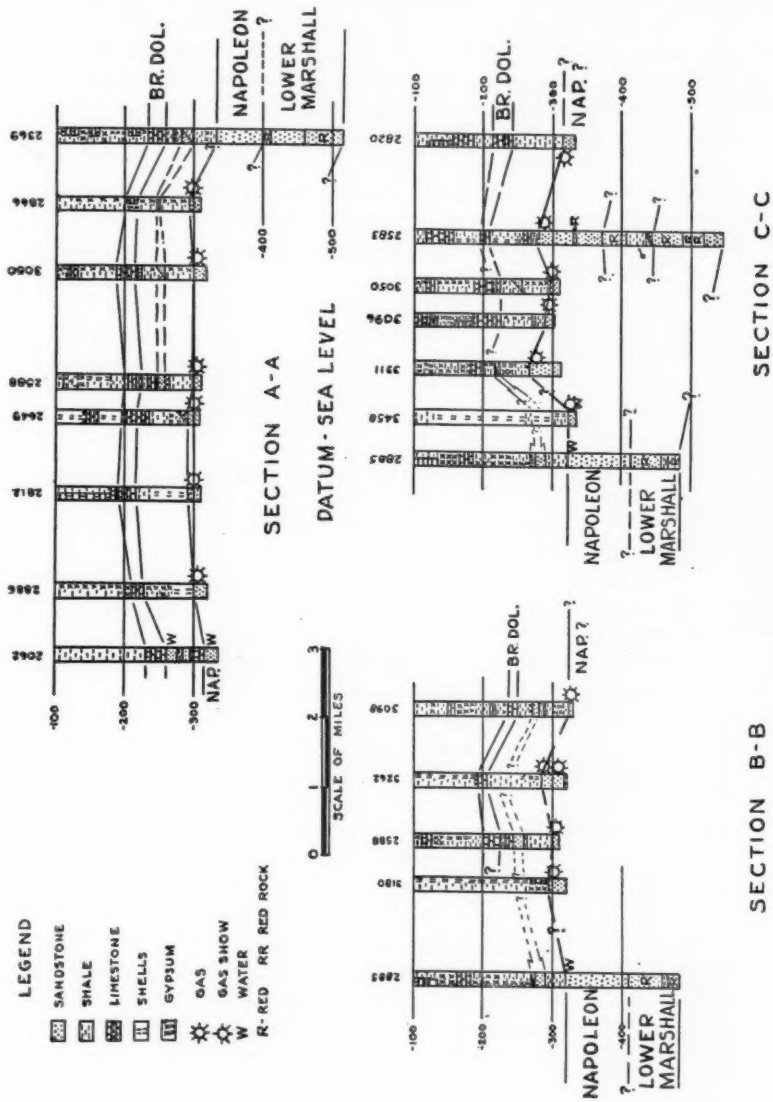


FIG. 13.—Cross sections of Six Lakes gas field.

AUSTIN GAS FIELD

Location.—The Austin gas field is in northern Austin and southern Colfax townships, Mecosta County, about 15 miles northwest of the Six Lakes area, on the same fold. Since the first commercial production on this fold was obtained in the Austin field, the general structure has been called the "Austin high."

Economics.—Thirty-one wells have been drilled in the field. Of these, 21 cut commercial flows of gas, 4 contained showings of gas, and 6 were dry holes. A well in Section 6, Morton Township, about 2 miles east of the field, contained a showing of gas in the lower part of the Michigan formation. Another well in Section 23, Martiny Township, approximately 7 miles northeast of the field, struck commercial quantities of gas in the same part of the section. Both these wells are definitely off the main structure and, as will be discussed later, the gas occurs in sands that apparently are stratigraphically higher than the "pay" in the main portion of the field. Offsets to these wells are dry.

The average initial open flow of the field wells has been calculated to be 5,880,000 cubic feet per day per well, and the productive thickness of the sand is about 9.6 feet.[35] A few wells were drilled to the Dundee, but no oil was found.

Stratigraphy.—The Michigan and Marshall formations in the Austin area are very similar to their equivalents in the Six Lakes field. The Michigan is about 330 feet thick and consists of blue, gray, and black shales with beds of gypsum, anhydrite, and dolomite. Well logs suggest that the section is generally more shaly than in the Six Lakes field and that the dolomites are not as well developed. The brown dolomite occurs about 250 feet below the top of the Michigan and averages about 15 feet in thickness. Below the brown dolomite are 60–70 feet of gray shales, gypsum, and anhydrite, with a few layers of limestone and dolomite and a few thin lenticular sands.

The contact between the Michigan and Marshall formations is similar to that described in the Six Lakes area. The section becomes very sandy and grades into the Marshall formation with only a slight change in sand appearance. The gas occurs in the upper part of the main sand body in the section, and the producing sands may be of Michigan or Marshall age. As in Six Lakes, the gas sands are generally gray and partially cemented, and the water-bearing sands on the edge of the field are lighter in color and comparatively uncemented. Again, the well logs generally limit the term "stray" to the gas-bearing sands, and the term "Napoleon" to the water sands.

[35] U. S. Bureau of Mines, *op. cit.*, p. 35.

Graphic-log correlations (Fig. 15) show that, as in the Six Lakes field, the top of the "Napoleon" in the edge wells is apparently equivalent to the top of the gas sand in the producing part of the area. A few shale breaks are present in the upper part of the sand, and the tight zone occurs between the gas and water sands.

As previously mentioned, the distinction between the two types of sand does not seem to be sufficient to indicate a definite separation, or to definitely place the gas sand in the Michigan formation, and the brine sands in the Marshall.

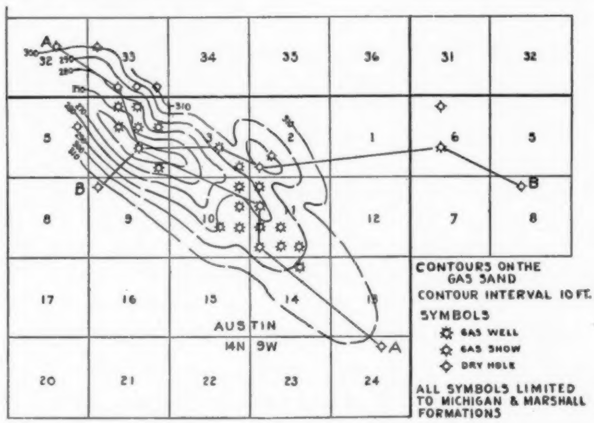


FIG. 14.—Structural map of Austin gas field.

The few deep tests in or near the field indicate a Marshall section similar to that described in the Six Lakes field. They also record a thinning of the Marshall section westward and southwestward, and it is probable that the conditions of the thinning are comparable to those previously discussed in the Crystal and Six Lakes areas. A correlation of logs of the field wells with those of the two gas wells east and northeast of the field seems to show that the gas in the latter is found in sands that are stratigraphically higher than the main "pay" of the Austin field (Fig. 15). Moreover, it appears that the gas does not occur in the same sand in both wells, but that the producing horizon in the well in Section 23, Martiny Township, is stratigraphically higher than the gas sand in the well in Section 6, Morton Township.

Structure.—The structural map (Fig. 14) contoured on the top of the "pay" shows a northwest-trending anticline that is steepest in the

northwest part of the field. Gas occurs farthest down the eastern flank—a condition similar to that discussed in the Clare and Broomfield areas and possibly due to the same causes.

The cross section (Fig. 15) shows the general association of gas occurrence with the highest area of the sand, and the apparent correlation of the producing sand with the Napoleon sandstone on the edge of the field.

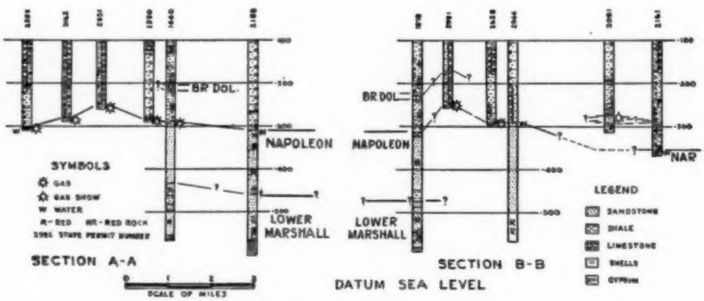


FIG. 15.—Cross sections of Austin gas field.

GENERAL RELATION OF CRYSTAL, SIX LAKES, AND AUSTIN FIELDS

The Michigan and Marshall formations are alike in all fields on the Austin "high," and the entire area can be considered a general stratigraphic unit. The gas occurs in sands at the base of the Michigan formation, the top of the Marshall formation, or both. It is very difficult to determine the contact between the two formations, and accordingly, the exact age of the producing sands.

The gas- and brine-bearing sands differ slightly in appearance, and in places thin beds of shale and dolomite are associated with the gas sands. A tight zone also lies between the gas- and water-bearing horizons. These criteria have been used to limit the gas sands to the Michigan formation and the water sands to the Marshall.

In the Six Lakes and Austin fields, however, the producing sands correlate very well with the brine-bearing horizons in the edge wells. The writer, therefore, believes that in this area there is no definite depositional break between the Michigan and Marshall formations, merely a change from a predominantly sandy series below to a shaly series above. The gas sands, then, may be of Michigan or Marshall age, or both.

In the Crystal area, there seems to be a relation between sand deposition and structure that implies sand concentration in areas of

shallow water that corresponded in location with the present structural "highs." Such a condition is not apparent in the Six Lakes and Austin fields.

The separation of the Napoleon sandstone and lower Marshall formations in the fields on the Austin "high" is also difficult due to the presence of red sands in the upper part of the Marshall section and light-colored sands in the lower part.

The Marshall section thins toward the west and southwest across the main structure. This thinning seems to be confined to the lower part of the Marshall, and may be due to an overlap of the lower Marshall on the Coldwater.

In the Crystal area, cross sections based on the brown dolomite or lower Marshall and Coldwater contact as datum planes show a definite thinning of the "Dundee to brown dolomite," or "Dundee to Marshall interval" in the area of oil production. The condition is similar to that described in the Broomfield area and in the fields on the Greendale "high" and suggests pre-Marshall structure as an important factor in oil accumulation.

OTHER AREAS OF GAS PRODUCTION

The previously discussed fields include all the important gas areas in central Michigan. However, there is some other scattered production of minor importance.

In the Edmore field, a small Traverse oil field on the Austin "high" in Sections 3 and 10, Home Township, Montcalm County, two wells reported commercial gas volumes in Mississippian rocks. Five other wells in the same field contained showings of gas in the same part of the section. Inasmuch as all these wells were drilled for oil, the information available about the gas sands is lacking in detail. However, graphic logs seem to show that the gas occurs in sands that are stratigraphically equivalent to the producing sand in the Six Lakes field. In addition, some of the gas was found in red sands, which suggests that the gas-producing horizons are of Marshall age.

In ten other scattered wells in Home, Richland, and Day townships, apparently on the edge of the Austin "high" in that area, there were showings of gas and commercial open flows up to about 3 million cubic feet per day. The well logs do not shed any additional light upon the exact age of the producing sands or on the Michigan and Marshall stratigraphy in that area, but the sands are either at the base of the Michigan formation or in the top of the Marshall.

In Aetna Township, Mecosta County, in two wells in Section 22 the records showed small quantities of gas near the top of the Mar-

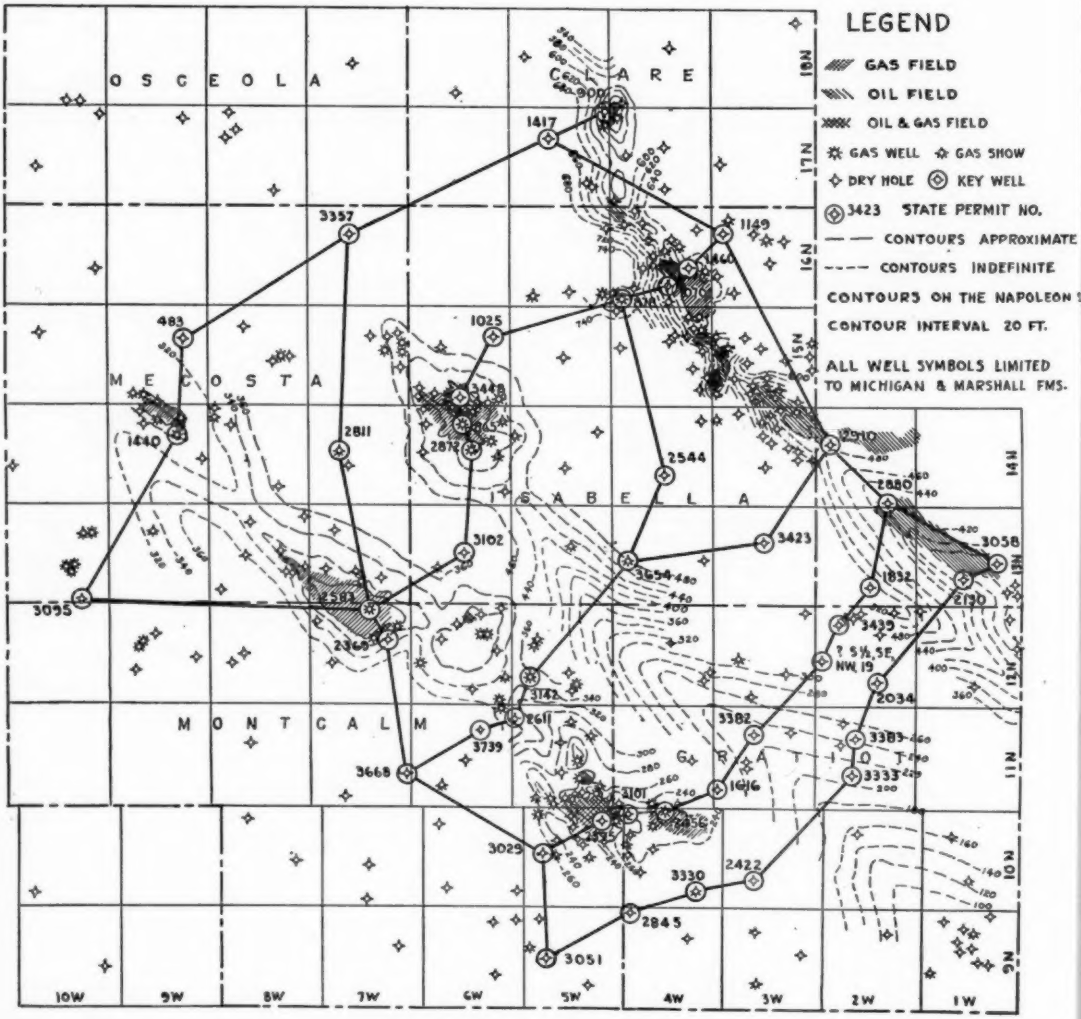


FIG. 16.—Structural map of central Michigan showing location of key wells and "fences" used in stereographic diagram.

shall, or the base of the Michigan formation. In a well in section 11 there was a showing of gas about 70 feet below the top of the Marshall. In another, in Section 37, there was an open flow of about 800,000 cubic feet per day from a sand approximately 250 feet below the top of the Michigan. Offsets to these wells were dry.

A well in Section 17, Winfield Township, Montcalm County, cut a commercial flow of gas at a depth of 1,144 feet below the surface in a sand that is recorded as the Napoleon sandstone, but may be of Michigan age.

Records of several other wells in the central Michigan area have reported small volumes of gas in the Michigan or Marshall formations, but available information is not sufficient to add to the previously discussed stratigraphy.

Conclusions

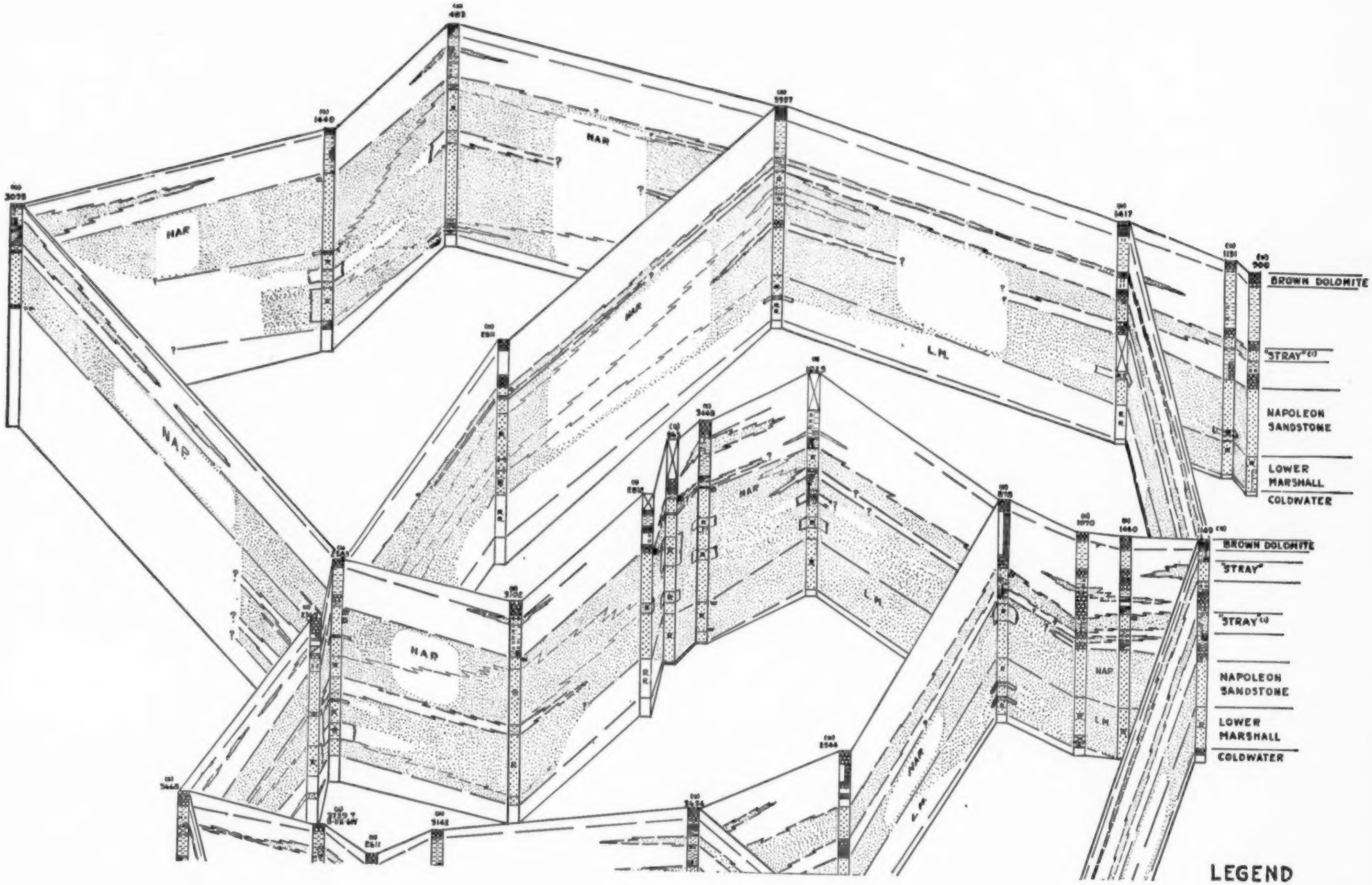
STRATIGRAPHIC RELATIONS IN CENTRAL MICHIGAN

The stereographic diagram (Fig. 17) shows the general stratigraphic relationships of the Michigan and Marshall formations in the area studied. The well logs used in the construction of this diagram were picked as key wells, and wherever possible, sample logs were used. In addition, these were correlated with other well records that do not appear in the diagram.

The stratigraphy of the Greendale "high" is shown in the northeastern (right hand) "fence." Here the Michigan and Marshall formations are fairly uniform in thickness and lithology, although the lower part of the Michigan is generally more sandy on structure than off structure. Regionally the sand content increases toward the southeast and decreases toward the north and northeast. The Marshall formations also thin toward the northeast, and the upper part of the Coldwater formation, which is not shown in the diagram, grows increasingly more sandy southward and southeastward along the Greendale fold.

It is also apparent that the gas-bearing stray sand of the Clare, Vernon, and Leaton fields grades into the top of the Napoleon southwest of the Greendale "high" as the intervening layers thin and disappear. If this is true, the top of the Napoleon sandstone in the central part of the area is stratigraphically higher than the so-called top in the eastern and northeastern part of the area.

Likewise, the sands at the base of the Michigan in the Broomfield and Crystal areas are probably comparable to a sandy phase of the Michigan formation in the area of the Greendale "high," which is somewhat higher in the section than the gas sands in the Clare,



BROWN DOLOMITE
"STRAY"(?)
NAPOLEON SANDSTONE
LOWER MARSHALL
COLDWATER
BROWN DOLOMITE
"STRAY"
"STRAY"(?)
NAPOLEON SANDSTONE
LOWER MARSHALL
COLDWATER
NAP
L.M.
LEGEND

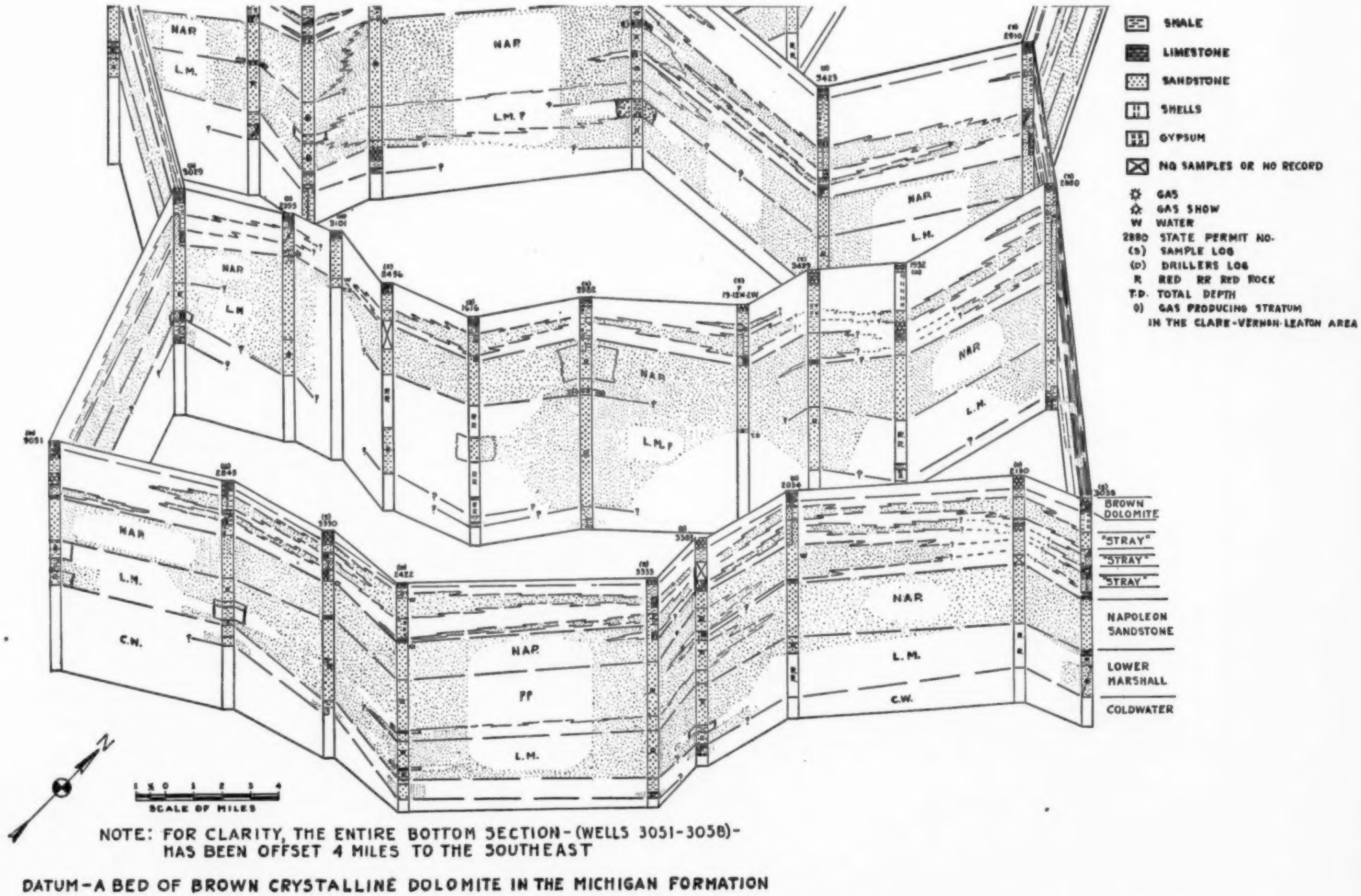


FIG. 17.—Stereographic diagram showing stratigraphic relationship of Michigan "stray sands" and Napoleon and lower Marshall formations.

Vernon, and Leaton fields. In turn, the stray sands of the Broomfield and Crystal areas might grade into the Napoleon at other points.

The contact between the Napoleon sandstone and the lower Marshall formation can be followed for some distance southwest of the Greendale fold. Finally, however, in the central part of the area, it is obscured by the appearance of red sand in the lower part of the Napoleon. Still farther southwest also the color distinction is noticeable, although it is problematical whether the two members of the Marshall here are equivalent to their eastern counterparts. In addition, the thinning of the Marshall in the western part of the area makes regional correlations even more difficult.

The unconformities that have been postulated between the lower Marshall, Napoleon, and Michigan formations in the eastern part of the state may be present on the edges of the area studied. Local conglomerates noted in a few well logs in the area farther west intimate the existence of unconformities and suggest near-shore deposits which have been worked over by waves or strong currents. These conglomeratic layers, however, are very lenticular, can not be correlated with any certainty over even short distances, and in view of the gradational relations already discussed, are not thought to be particularly significant.

The relation between the upper part of the Marshall formation and the lower part of the Michigan in the area studied suggests a deltaic or littoral deposit in comparatively shallow water. The area of the greatest sand deposition appears to be in the central and south-central parts of the region. Toward the north and northeast, the material grew finer as the distance from its immediate source was increased, and the lower part of the Michigan formation in the northeastern part of the area seems to be an off-shore phase of the Marshall farther west.

The sand, shale, and limestone zones in the lower part of the Michigan suggest variations in the intensity of erosion of the adjacent land masses or intermittent shifting of the delta distributaries. These periods may have been accompanied by an epeirogenic oscillation of the entire area and a consequent change in the depth of the water in which the sediments were being deposited. The brown dolomite probably marks a definite decrease of the erosion of the adjacent land masses, for most of the sand bodies occur below this layer.

The local increase of the sand content in the lower part of the Michigan formation in some areas that are structurally high at present implies that these areas were slightly higher at the time of the sand deposition than those on either side, that the sand was concentrated in the areas of shallow water, and that in Michigan time the

structures were probably subdued but generally located along the same trends as the present folds.

No doubt some of the sand in the lower part of the Michigan formation is reworked Marshall. Since there does not seem to be any evidence of a definite unconformity between the Michigan and Marshall formations in the central part of the area studied, the exact contact between these formations is difficult to determine. Accordingly, the conception is not justified that the gas in the central part of the area is confined to sands of Michigan age and that the Marshall produces only brine. The fact, also, that the gas-producing stray sands in the Clare, Vernon, and Leaton fields are apparently fingers of the Marshall formation suggests that the stray sands in other localities might have been similarly formed.

SIGNIFICANCE OF GAS OCCURRENCE

The study of the gas fields in the central Michigan area reveals the most important factor in delineating gas occurrence to be the actual elevation of the upper surface of the gas sand. This elevation is determined by regional and local structure and local variations in the thickness of the sand.

In some localities, such as the Crystal oil and gas area and areas on the Greendale "high," the lower Michigan formation is more sandy on structure than off structure. The condition is apparently due to the influences of crustal warping or gentle folding at the time of sand deposition.

Such sand concentration undoubtedly affects or limits gas production, for increased sand thickness on structural "highs" would produce a greater closure on the top of the sand than that on the underlying structure.

Similarly, local depositional structures due to slight variations in the position of an individual sand in the vertical stratigraphic column can change the closure on top of the sand from that of a reflection of the regional structure, and thereby affect or limit gas occurrence.

These factors plus porosity variations are locally important. However, the fact that the major gas fields are all located over Marshall "highs" shows that the regional structure is apparently the most important factor in controlling the elevation of the sand and in limiting gas occurrence.

SOURCES OF GAS

The Mississippian gas probably did not originate in its present reservoir beds, because the organic content of the sands is extremely low. In some of the fields black shales are closely associated with the gas-producing horizons. This condition, coupled with the presence of

small quantities of heavy oil in the gas sands of the eastern part of the area seemingly might suggest that source beds of the oil and gas were not far removed from the sand. It is not probable that the oil could migrate for any great vertical distance through the impervious shales and dolomites of the Michigan formation.

Nevertheless, it must be noted that most of the gas occurs in or near the top of the Marshall formation. It is possible, therefore, that the gas used the Marshall sands as a pathway for migration, and, although some of the probable source beds are in contact with the upper part of this formation, it seems likely that part of the gas originated at a greater depth, perhaps from the shales of the Coldwater. The thought is strengthened by the fact that showings of gas have been reported some distance below the top of the Marshall.

As previously mentioned, no commercial quantities of Mississippian gas have been found on the Greendale "high" southeast of the Leaton field. The absence could be due to lack of closure on top of the sand, or poor source-bed conditions. The writer is inclined to favor the latter hypothesis, because the lower part of the Michigan formation and the upper part of the Coldwater generally grow increasingly sandy southeastward along the Greendale "high."

In this event, it is possible that the microscopic organic debris believed to be the basic source of oil and gas was not deposited in the area, but was carried farther out to quieter water. In addition the water of the Coldwater and Michigan seas may have become increasingly brackish toward the immediate source of the sediments. This might preclude the amount or type of bacteriological decomposition necessary for the origin of source rocks.[38]

It is, therefore, suggested that the Mississippian gas in the central Michigan area may have originated in either the Michigan or the Coldwater formation, or in both. It is also possible that the gas in the various fields did not entirely come from source beds of the same age. A detailed analysis of the constituents of the gases, together with a similar analysis of the possible source beds, should throw some light on this subject. Unfortunately such analyses are not available.

At the date of writing, considerable interest and drilling activity are centered in the region of Nottawa Township, Isabella County, about half-way between the Greendale and Broomfield "highs." This area is an important one in the determination of the exact stratigraphic relationship of the Michigan and the Marshall formations. As present information is limited to only a few scattered drillers' logs, it is hoped that future studies of well cuttings in this locality will aid in more thoroughly solving the problems presented and discussed in this paper.

[38] E. W. Hard, "Black Shale Deposition in Central New York," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 2 (February, 1931), p. 181.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 2 (FEBRUARY, 1938), PP. 175-188, 4 FIGS.

THE ORISKANY IN WEST VIRGINIA[1]

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Charleston, West Virginia

ABSTRACT

Commercial oil and gas possibilities from the Oriskany series of the Devonian in West Virginia were first demonstrated in 1918, but no commercial production was developed until 1930. In 1934–35 three fields, now having a proved area of 43,000 acres, were opened in Kanawha County.

The Oriskany sandstone is a sheet deposit in West Virginia and underlies approximately three-fourths of the state from its outcrop along the eastern edge before it thins and disappears in the western part. The sand ranges in thickness from probably more than 200 feet in the northern part to an average of 40 feet in the producing fields. A very definite water table is present on the eastern margin of the gas belt. This is apparently trapped water, as rock pressures in the Kanawha County fields do not indicate hydrostatic control. The sand varies from coarse-grained (1.+millimeter) to fine-grained (0.1 millimeter) sand. Normally, the upper part of the sand is much coarser than the middle or lower section; however, alternate coarse- and fine-bedded sand is very common and is very suggestive of cross-bedding. Calcium carbonate is the main cementing material in the sand, although near the western limits of deposition silica is the predominating cementing medium. Porosity in the proved fields ranges from 6.8 to 11 per cent. Open flows in the various fields range from 46,000 to 22 million cubic feet, with rock pressures varying from 1,100 to 1,940 pounds. Carbon dioxide and distillate are present in the gas in these fields. The carbon-dioxide content of the gas increases in wells high on the structure, while the distillate decreases. To date, 21 dry holes and 124 gas wells have been completed, and a daily open flow of 625,725,158 cubic feet developed. Anticlinal structure is of primary importance for production, but proper sand conditions are also necessary. Due to convergence, anticlines, as expressed on the deeper horizons, are shifted from their surface or shallow subsurface location. The reflection seismograph has been a very valuable aid in checking the positions of these axes and will, no doubt, help materially in areas where water is thought to be present.

INTRODUCTION

The Oriskany group was classified and subdivided by the Maryland Geological Survey and, where applicable, the Maryland correlation was accepted and used by the West Virginia Geological Survey.[3]

In West Virginia the Ridgeley sandstone member of the Oriskany (Fig. 1) is correlative with the Oriskany sand of the driller and is the main producing member of this series. Recently, commercial gas has been produced near Uniontown, Fayette County, Pennsylvania, near the crest of the Chestnut Ridge anticline in the Huntersville chert member, which directly overlies the Ridgeley (Oriskany) sandstone. The Huntersville chert has several sandy phases, but, until the recent

[1] Read before the Association at the mid-year meeting in Pittsburgh, October 15, 1937.

[2] Assistant geologist, The Owens, Libbey-Owens Gas Department.

[3] Paul H. Price, "The Oriskany Group (Areal) of West Virginia," *Oriskany Sand Symposium* (Appalachian Geological Society, 1937), pp. 5–13.

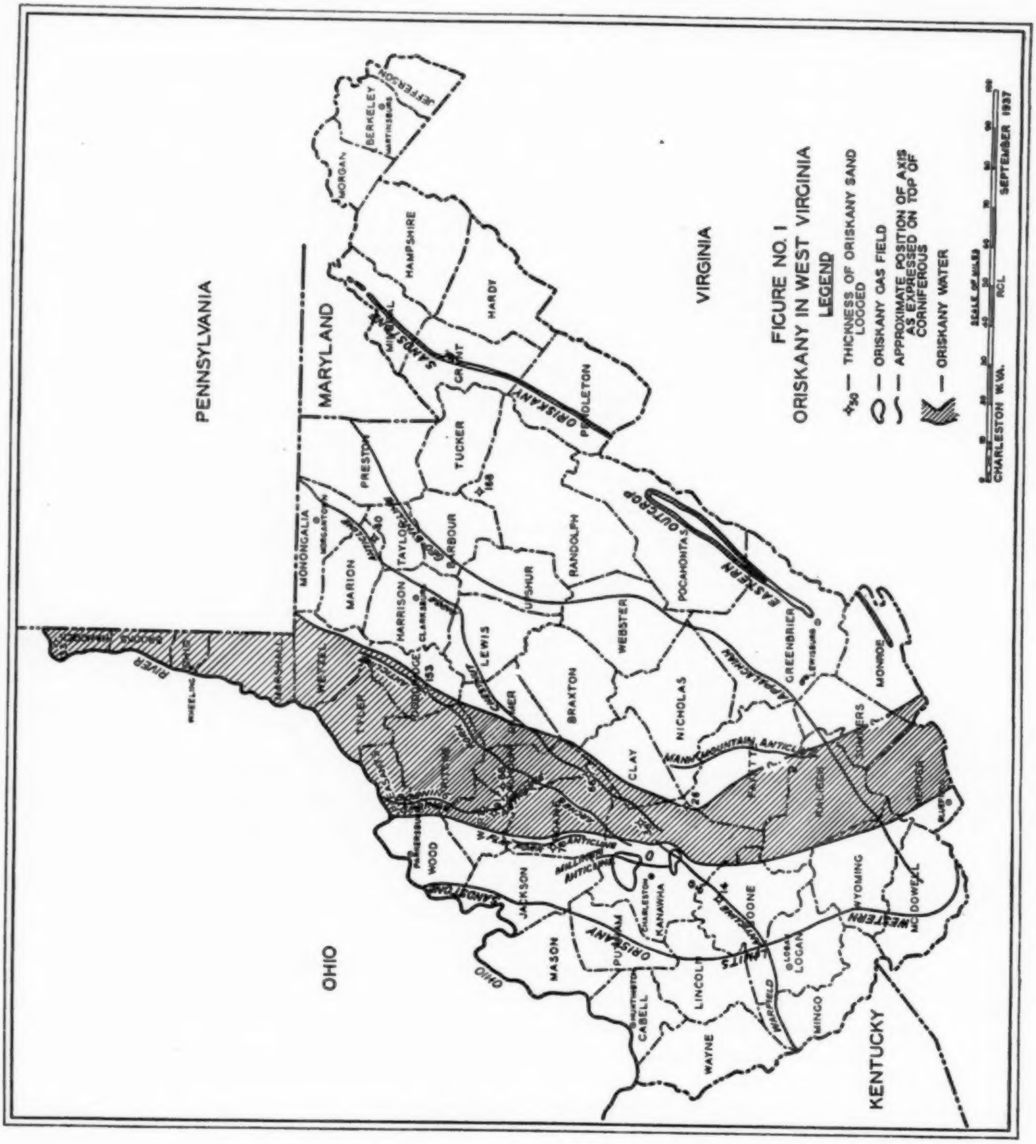

PENNSYLVANIA
MARYLAND
VIRGINIA
OHIO
KENTUCKY
FIGURE NO. 1
ORISKANY IN WEST VIRGINIA
LEGEND
THICKNESS OF ORISKANY SAND LOGGED
ORISKANY GAS FIELD
APPROXIMATE POSITION OF AXIS AS EXPRESSED ON TOP OF CORNIFEROUS
ORISKANY WATER
CHARLESTON W.VA.
RCL
SEPTEMBER 1937

Fig. 1

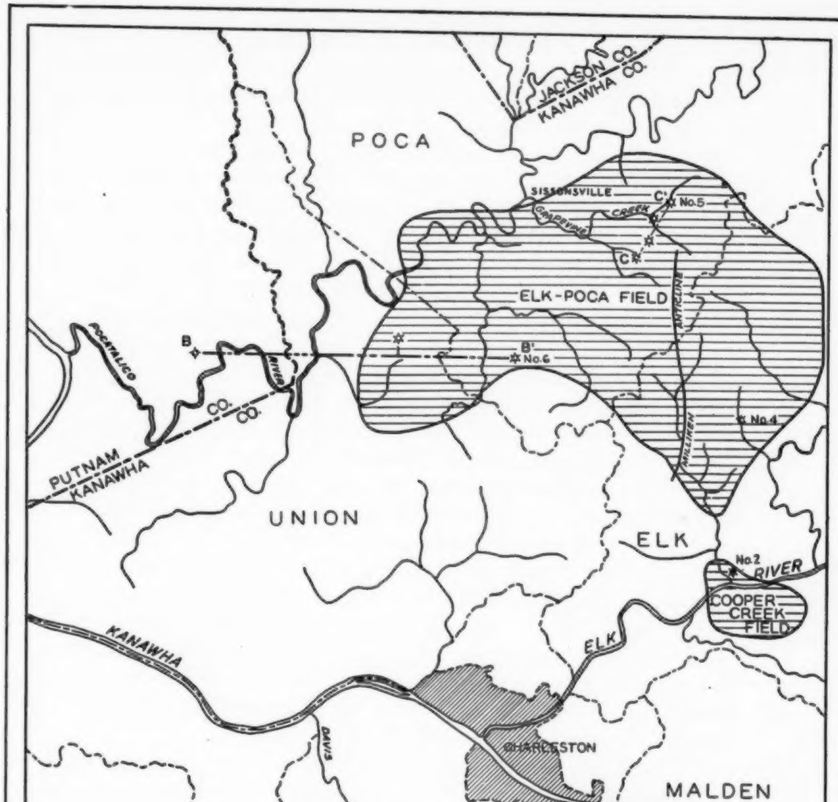


FIGURE NO. 2
ORISKANY GAS FIELDS
KANAWHA CO.
WEST VA.
LEGEND
NO.1 — DISCOVERY WELL
— GAS FIELD
A—·—A' — CROSS SECTION
SCALE OF MILES
SEPT. 1937
R.G.L.
JACKSON CO.
KANAWHA CO.
POCA
SISSONSVILLE
GRAPEVINE
CREEK
No.5
ELK-POCA FIELD
ANTICLINE
MILLIKEN
No.6
No.4
POCATALICO
RIVER
PUTNAM
KANAWHA
CO.
UNION
ELK
No.2
RIVER
COOPER CREEK FIELD
KANAWHA
ELK
CHARLESTON
MALDEN
DAVIS
CREEK
WASHINGTON
CAMPBELL
CAMPBELL - DAVIS CREEKS FIELD
No.3
LOUDON
ANTICLINE
No.1
BELLE
RIVER
KANAWHA
BOONE
RIVER
WARFIELD
COAL
CABIN CREEK

FIG. 2

production near Uniontown, has not been given much consideration as a commercial gas horizon.

Several scattered dry holes were drilled through the Oriskany formation in the state prior to the recent discovery of commercial gas in Kanawha County. Well No. 4670 of the Hope Natural Gas Company, drilled in 1918, on the Volcanic Oil and Coal Company property in Wood County, West Virginia, near the crest of the Burning Springs anticline, encountered gas in either the top of the Huntersville chert "Corniferous" or in the Oriskany sandstone. This well is variously reported as having an original open flow ranging from 200,000 to 2 million cubic feet. Water was encountered below the gas and the well was abandoned. This well is the earliest test of which the writer has a record that demonstrated possibilities of commercial production in the state from the Oriskany formation.

Following this early well, no commercial wells were developed in the Oriskany until September, 1930, when the United Fuel Gas Company completed its No. 4067 (No. 1 on Fig. 2) on the Black Band Coal and Coke Company property on the waters of Davis Creek, Loudon District, Kanawha County, high on the north flank of the Warfield anticline. In this well 527,000 cubic feet of gas was encountered in a white sandstone 90 feet below the top of the "Corniferous lime." This white sand is correlative with the Ridgeley sandstone member of the Oriskany and was the first commercial Oriskany (Ridgeley) gas well developed in West Virginia.

During 1932–33 Grosscup *et al.* drilled three small gas wells on the waters of Cooper Creek in Elk District, Kanawha County, on or near the crest of the Milliken anticline. These wells produce from a white sand encountered from 102 to 115 feet below the top of the "Corniferous lime" and had original open flows ranging from 46,000 to 143,000 cubic feet. Due to the economic depression and the small open flows, these wells attracted very little attention. With the completion in September, 1934, of the W. L. Burdette No. 1 (No. 2 on Fig. 2) by Grosscup *et al.*, producing oil and gas from a white sandstone 108 feet below the top of the "Corniferous lime," and variously reported as having a flush production varying from 50 to 200 barrels of oil with some gas, active interest was aroused and a very intensive but localized leasing campaign ensued. Several offset wells were begun and were completed as either gas wells or dry holes through the Oriskany sand.

In March, 1935, Godfrey L. Cabot, Inc., completed their No. 807 (No. 3 on Fig. 2) on the Campbells Creek Coal Company property on the waters of Campbells Creek, Malden District, Kanawha

County, encountering the Oriskany 99 feet below the top of the "Corniferous lime." This well had an inital open flow of 2,182,000 cubic feet and opened the Campbells Creek field. As this well was several miles south of the Burdette well, and as most of the intervening territory was not available for leasing, as leases were held by shallow producing wells, no extensive leasing program was possible. However, considerable excitement and some scattered leasing ensued.

With the completion of the Copenhaver Heirs No. 1 (No. 4 on Fig. 2), by the Columbian Carbon Company on Lick Branch of Little Sandy Creek, Elk District, Kanawha County, with an open flow of 2,630,000 cubic feet from the Oriskany in an area of small ownership properties, an active and widespread leasing campaign and drilling program were begun. At the present time practically all of the major companies are drilling offset locations, or semi-wildcat wells near the edges of proved fields, and very little wildcat drilling is being done. Following is the total proved area developed to date; as yet the limits of the three fields have not been completely defined.

	Acres
Cooper Creek field	1,800
Campbell-Davis Creek field	9,600
Elk-Poca field	31,600
Total proved area	43,000 (September 30, 1937)

AREAL EXTENT OF ORISKANY SAND

On Figure 1 the eastern outcrop of the Oriskany (Ridgeley) sandstone is shown. This is taken from the map of the "Oriskany Sand and Devonian Shale" prepared by the Appalachian Geological Society.[4] The western limits of the Oriskany are also shown. This western limit is difficult to define due to lack of drilling as well as lack of accurate information and well cuttings from past drilling. No doubt, this western limit will be modified when additional data are available. Possibly outliers and isolated fields west of the main limits may be discovered such as have been found in Ohio.[5]

Commercial gas production has been found in Columbiana County, Ohio, as well as in Beaver County, Pennsylvania, near the tip of the West Virginia Panhandle and definitely proves the existence of the Oriskany sand sheet in the northwestern part of the state. In Doddridge County the test of the Columbian Carbon Company logged 153 feet of Oriskany sand. It is apparent that nearly three-fourths of the state will be found to be underlain with Oriskany sand

[4] *Oriskany Sand Symposium* (Appalachian Geological Society, 1937), Map No. 1, in pocket.

[5] J. R. Lockett, "The Oriskany Sand in Ohio," *ibid.*, pp. 61–64.

(Ridgeley) and that it will be found to have a thickness of possibly more than 200 feet in the northern part of the state, gradually thinning and disappearing in the western part. On Figure 1, several scattered wells throughout the state where the Oriskany is definitely present are shown with the sand thickness as logged.

There is some evidence to indicate that the Oriskany was deposited on an eroded surface, but deposition does not appear to be as erratic as that described by Paul D. Torrey[6] as existing in central New York and northern Pennsylvania. Apparently the Oriskany sea deposition was fairly regular over areas of slight structural relief, but was truncated or deposited as a relatively thin sheet over areas of high structural relief, such as the Warfield and Burning Springs anticlines.

WATER IN ORISKANY SANDSTONE

Figure 1 also shows the approximate position of the Oriskany water table throughout West Virginia. Evidently, this belt of water is somewhat similar to the rim water encircling productive anticlines in northern Pennsylvania and southern New York. Water encountered in some wildcat wells has risen as high as 3,000 feet in the hole, but tests east of this water belt have proved completely dry, with calcium-carbonate cemented sand. Apparently, there is little connection between this water and the Kanawha County Oriskany gas fields, as rock pressures do not indicate hydrostatic control.

ORISKANY SANDSTONE

The Oriskany sandstone, when examined from well cuttings, is seen to be clear glassy sand varying from a coarse grain (1.+ millimeter) to a very fine grain (0.1 millimeter). The sand is normally coarser-grained in the upper part of the formation than in the middle or lower part. As there is considerable variation from well to well with alternate coarse- and fine-grained sand appearing without any definite order, it is apparent that in the area of the present gas fields, the Oriskany has been deposited in relatively shallow water and has been at least locally cross-bedded. Grains are normally sub-angular to sub-round, with frosted grains here and there throughout the sand. Some small pebbles (3–6 millimeters in diameter) are noted, but to date no definite conglomeratic horizon has been found.

A "break" normally occurs near the middle of the sand and varies from a few feet of calcium-carbonate cemented sand to shaly lime-

[6] Paul D. Torrey, "Natural Gas from Oriskany Formation in Central New York and Northern Pennsylvania," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 6 (June, 1931), pp. 671–88.

stone. In the eastern part of the Elk-Poca field the "Big pay" is below this break, in sand varying from 0.35 to 0.4 millimeter in diameter. In the northern and western part of this field, the "pay" is above this break in a somewhat coarser sand. A few wells have logged a third "pay," but this lower gas zone is apparently not as regular as the upper two.

Cementing material in this sand is ordinarily calcium carbonate, although dry holes near the western limits of the sand have considerable siliceous cement. Porosity and the amount of cementing material in the sand vary greatly over the field. Wells high on structure ordinarily have more cementing material than wells farther down on the flanks. Tests made on several scattered wells indicate porosity ranging from 6.8 to 11 per cent.

HUNTERSVILLE CHERT

Immediately overlying the Ridgeley sandstone members of the Oriskany is the Huntersville chert, also of Oriskany age. In New York and Pennsylvania this formation below the Marcellus shale and above the Oriskany (Ridgeley) is considered of Onondaga age. Whether the Onondaga disappears in the overlying Marcellus or grades into the Huntersville chert, is not definitely established. However, working solely from lithologic evidence, the writer knows that this section in the Kanawha County fields can be correlated with the section in Bradford County, Pennsylvania. This section is predominantly an extremely cherty limestone or more properly a calcareous chert, with several sandy and glauconitic zones that can be readily correlated. In the upper part the chert appears to be secondary replacement, but in the middle and lower parts it appears to be bedded. Several wells have logged showings of oil and gas in the upper part of this member, but no wells in the state have been commercially productive.

KANAWHA COUNTY ORISKANY FIELDS

In this preliminary paper information is drawn principally from company files, although much information has been obtained from geologists of other companies interested in this area who have aided through mutual exchange of thought and data. A detailed treatise can be given at a later date when additional information is secured and is no longer considered confidential.

The producing area developed to date in Kanawha County is divided into three fields, which are shown in Figure 2. As mentioned previously, the limits of these three fields have not been completely defined. At present, they embrace 43,000 acres and extensions will,

in all probability, bring the total proved area to 75,000 acres. The following names are used merely for convenience in writing. The Elk-Poca field is known locally as Aaron Fork, Grapevine, Cooper Creek, *et cetera*. The Cooper Creek field, as the name is used in this article, could very easily embrace the southern tip of the Elk-Poca field, due to similar rock pressures, similarity in gas analyses, structural conditions, *et cetera*, but due to an intervening dry area it is shown as a separate field. Similarly, the Campbell-Davis Creek field will probably embrace an area, when limits are defined, that extends beyond these drainages, but as these names are in such common usage it was thought best to use them.

STRUCTURE

Due to convergence in the thick Devonian shales, anticlinal structures are shifted on the deeper formations from their surface or shallow subsurface positions. This shifting is very slight on anticlines with north-south axis, but on northeast-southwest anticlines the shifting may be as great as 2 miles. Figure 2 shows the axis of the Milliken anticline as projected by use of a convergence map from a shallow subsurface structural map to the top of the "Corniferous." This axis is considerably distorted due to a complicated fault pattern. Detailed seismograph surveying has shown two well developed trends that have only slight surface indications. Apparently, two periods of faulting are present. First a major north-south pattern that was evidently the prime factor in the formation of this anticline, as the structure is more suggestive of an underthrust fault than of a true anticline. The first faulting was later followed by a northeast-southwest pattern of normal faulting which sheared across the structures as formed by the first movement. The Milliken has extremely steep dips on the east side of the field, but the crests of the closures in this general area are relatively flat, as shown by cross sections *BB′* and *CC′*.

COOPER CREEK FIELD

The Cooper Creek field was opened with the completion of the W. L. Burdette No. 1 (No. 2 on Fig. 2) by Grosscup *et al.* in September, 1934. This well was completed as a flowing well and was variously reported as having a flush production of 50–200 barrels. This rapidly declined to settled production at 22 barrels of oil and 200,000 cubic feet of gas. Several other wells were completed ranging from 900,000 to 5,160,000 cubic feet, with initial rock pressures varying from 1,340 to 1,490 pounds. This field is apparently a transition between the Elk-Poca field on the north and the Campbell-Davis Creek field on the south. A small amount of distillate is produced with the

gas, but much less than the quantity produced in the Elk-Poca field.

With the exception of the southern edge of the Campbell-Davis Creek field, this field is more faulted and complicated than any other. The main axis can probably be drawn north and south paralleling the Milliken, but may depart from this trend due to the warping effect caused by faulting. The field judged from gas deliveries and other indications, suggests the presence of small *en échelon* structures.

CAMPBELL-DAVIS CREEK FIELD

The Campbell-Davis Creek field was opened in March, 1935, by G. L. Cabot, Inc., with the completion of their No. 807 (No. 3 on Fig. 2) on the Campbells Creek Coal Company property. Open flows throughout the field range from 260,000 to 7,787,000 cubic feet with rock pressures from 1,100 to 1,295 pounds. The gas confined in this field is essentially a dry gas, as only a small amount of distillate is produced. This field differs materially from the Elk-Poca in that the gas contains a high percentage of carbon dioxide.

The field is traversed northeast and southwest by the Warfield anticline. The axis as shown is based on the top of the "Corniferous" limestone and was projected by use of a convergence map from a shallow subsurface horizon. Water is found on the south side of the field, but although the rock pressure of the field has fallen off to approximately 700 pounds, water has appeared in only one well. Here water may have migrated along a fault plane, as offset wells only a few feet structurally higher are completely free of water.

ELK-POCA FIELD

The Elk-Poca field was opened by the completions of the Copenhaver Heirs No. 1 (No. 4 on Fig. 2) by the Columbian Carbon Company in August, 1935, the D. A. Griffith No. 1 (No. 5 on Fig. 2) commenced by Ziebold and later purchased and completed by the West Virginia Gas Corporation in April, 1936, and the G. W. Facemeyer No. 1 (No. 6 on Fig. 2) by the United Carbon Company in November, 1936. Open flows throughout the field range from 2 million to 22 million cubic feet with rock pressures ranging from 1,880 to 1,940 pounds. In the southern tip of this field open flows range from 46,000 to 3,300,000 cubic feet with rock pressures of 1,530–1,750 pounds. Practically all of the wells in this field produce a distillate (gasoline) along with the natural gas. Some of the wells in the northern part of the field yield as high as 700–800 gallons of distillate to 1 million cubic feet of gas produced. A slight trace of sulphur is found in this distillate, but is not present in the gas.

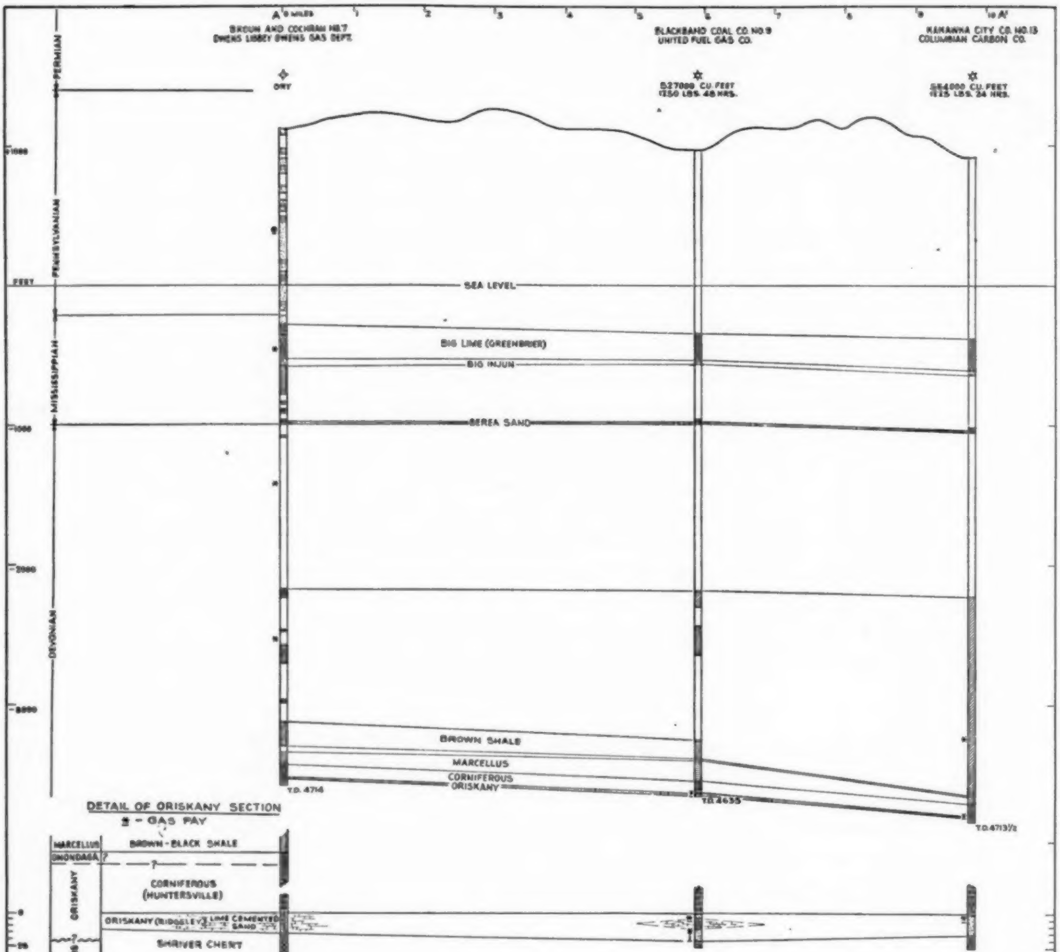
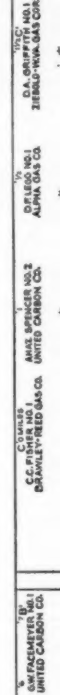

A 0 MILES
1
2
3
4
5
6
7
8
9
10 A'
BROWN AND COCHRAN NO.7
OWENS LIBBEY OWENS GAS DEPT.
BLACKBAND COAL CO. NO.9
UNITED FUEL GAS CO.
KANAWHA CITY CO. NO.13
COLUMBIAN CARBON CO.
DRY
PERMIAN
PENNSYLVANIAN
MISSISSIPPIAN
DEVONIAN
FEET
SEA LEVEL
BIG LIME (GREENBRIER)
BIG INJUN
BEREA SAND
BROWN SHALE
MARCELLUS
CORNIFEROUS
ORISKANY
T.D. 4714
T.D. 4635
DETAIL OF ORISKANY SECTION
- GAS PAY
MARCELLUS
ONONDAGA ?
BROWN-BLACK SHALE
ORISKANY
CORNIFEROUS
(HUNTERSVILLE)
ORISKANY (RIDGELEY)
LIME CEMENTED
SAND
SHRIVER CHERT
HELDERBERG
SEPTEMBER 1937 R.C.L.

FIG. 3



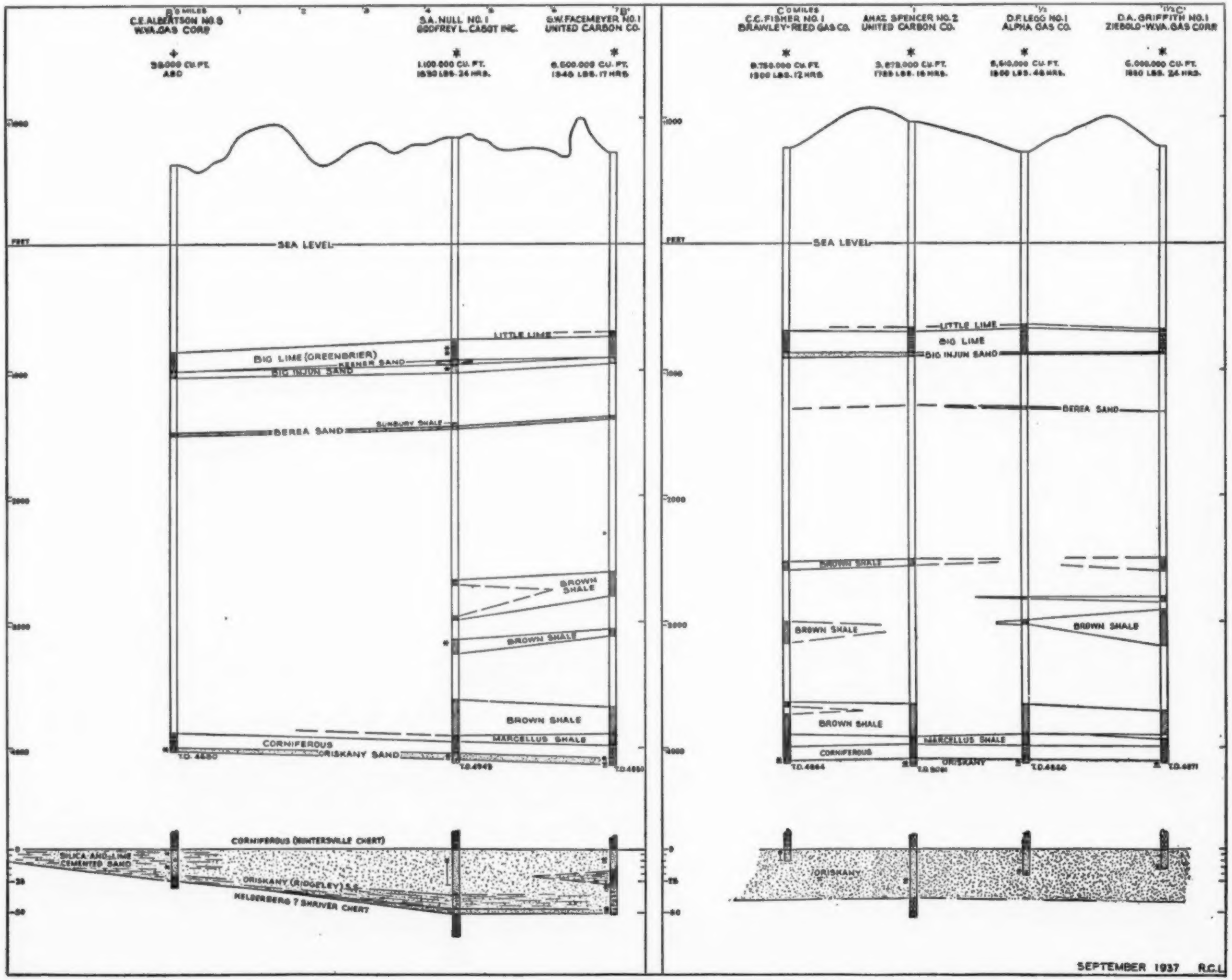

C.E. ALBERTSON NO. 5
W.VA. GAS CORP.
38,000 CU. FT.
S.A. NULL NO. 1
GODFREY L. CABOT INC.
1,100,000 CU. FT.
1650 LBS. 24 HRS.
S.W. FACEMEYER NO. 1
UNITED CARBON CO.
6,500,000 CU. FT.
1545 LBS. 17 HRS.
C.C. FISHER NO. 1
BRAWLEY-REED GAS CO.
9,750,000 CU. FT.
1500 LBS. 12 HRS.
ANAZ SPENCER NO. 2
UNITED CARBON CO.
3,878,000 CU. FT.
1755 LBS. 16 HRS.
D.F. LEGG NO. 1
ALPHA GAS CO.
5,510,000 CU. FT.
1800 LBS. 48 HRS.
D.A. GRIFFITH NO. 1
ZIEBOLD-W.VA. GAS CORP.
6,000,000 CU. FT.
1850 LBS. 24 HRS.
SEA LEVEL
FEET
LITTLE LIME
BIG LIME (GREENBRIER)
KEENER SAND
BIG INJUN SAND
BIG LIME
BEREA SAND
SUNBURY SHALE
BROWN SHALE
MARCELLUS SHALE
CORNIFEROUS
ORISKANY SAND
ORISKANY
T.D. 4650
T.D. 4949
T.D. 4850
T.D. 4864
T.D. 5091
T.D. 4860
T.D. 4871
CORNIFEROUS (HUNTERSVILLE CHERT)
SILICA AND LIME CEMENTED SAND
ORISKANY (RIDGELEY) S.S.
HELDERBERG ? SHRIVER CHERT
SEPTEMBER 1937 R.C.L.

FIG. 4

ORISKANY GAS ANALYSES, KANAWHA COUNTY, WEST VIRGINIA

Fractional Analyses by West Virginia Geological Survey	*Cooper Creek Field*	*Campbell-Davis Creek Field*		*Elk-Poca Field*		
	Well Near Fig. 2, No. 2†	*Fig. 2, No. 1**	*Fig. 2, No. 3**	*Fig. 2, No. 4**	*Fig. 2, No. 5**	*Fig. 2, No. 6*†
Methane	83.08	85.35	84.04	87.90	85.60	87.26
Ethane	10.51	6.24	7.59	7.38	7.16	6.58
Propane	3.70	2.00	2.37	2.26	2.28	2.27
Iso-Butane	.17	.25	.52	.12	.36	.33
N-Butane	1.11	.61	.66	.85	.86	.80
Tetramethyl methane		.07				
Iso-Pentane	.15	.07	.97	.11	.17	.15
N-Pentane	.30	.15		.26	.35	.29
Disopropyl	.04	.01		.02	.00	.00
Dimethylpropyl methane	.01	.07		.07	.17	.09
N-Hexane	.15	.07		.09	.14	.14
Iso-Heptane	.04	.04		.01	.06	.03
N-Heptane	.05	.03		.02	.07	.04
Octanes	.04			.02	.18	.06
Nitrogen	.65	.00	.40	.89	2.60	1.96
Carbon dioxide	.02	5.04	3.45	.00	.00	Trace
B.T.U. (30"Hg. 60°F.)	1,172	1,067	1,100	1,112	1,135	1,116
Sp. Gr. (Calo. Air-1)	.687	.680	.693	.651	.671	.652

* Data from company owning well.
† Data from Paul H. Price, "Analysis of Oriskany Gas in Kanawha County, West Virginia, with Some Interpretations," *Oriskany Sand Symposium* (Appalachian Geological Society, 1937), pp. 72–80.

COOPER CREEK FIELD, CRUDE OIL ANALYSES* (FIG. 2, NO. 2)

Per cent Crude	
Gravity	42.1
Color, O. D.	12
Appearance	Amber
Sulphur, per cent	0.19
Crude dist. per cent 410	28
Cut Gravities (25°C.)	
6	54.5
7	52.0
8	49.9
9	46.8
10	43.0
11	42.6
12	41.0
13	39.0
14	37.7
15	35.9
16	34.6
Bottoms	30.2
Additional Tests on Bottoms	
Per cent Crude	21.0
Flash, °F.	555
Fire, °F.	635
Pour, °F.	75
Vis. Grav. Const.	.788
Carbon Res.	0.35
Sulphur, per cent	0.15
S. U. Vis./210°F.	103

* R. C. Tucker, "Deep Well Records," *West Virginia Geol. Survey* (1936), p. 178.

FRACTIONAL ANALYSES OF ORISKANY DISTILLATE (DRIP GASOLINE)*
KANAWHA COUNTY, WEST VIRGINIA

	Campbell-Davis Creek Field	*Elk-Poca Field*	*Commercial Second Grade Gasoline*
	Per Cent	*Per Cent*	*Per Cent*
Ethane	.11	.24	.00
Propane	1.39	1.09	.00
Iso-Butane	.56	1.17	2.62
N-Butane	1.71	3.26	7.18
Iso-Pentane	1.70	.74	1.46
N-Pentane	4.17	5.98	8.68
Hexane and heavier	90.36	87.52	80.06
A.P.I. gravity of hexane and heavier residue	63.4°	63.6°	56.7°

* The distillate in these fields gives a very strong sulphur reaction to the "Doctors'" test. The sulphur is probably present in the distillate in the form of mercaptans.

SUMMARY OF DRILLING BY FIELDS, KANAWHA COUNTY, WEST VIRGINIA*
(SEPTEMBER 30, 1937)

	Dry Holes	*Drilling Wells and Active Locations*	*Gas Wells*	*Open Flow Developed*
				Cu. Ft.
Cooper Creek	5	5	8	18,017,000 25 bbls. oil per day
Campbell-Davis Creek field	9	7	38	69,229,118
Elk-Poca	7	93	78	538,479,040
Total	21	105	124	625,725,158

* Seven other deep tests are drilling throughout the state, but are outside of the Kanawha County fields.

GENERAL STATEMENT

The Oriskany sandstone, where productive in the Kanawha County fields, varies from 11 to 60 feet in thickness with the "pays" from 1 foot to 28 feet below the top of the sand. Where the sand is of greater or less thickness it has proved non-productive. This critical productive thickness is probably due to shore-line conditions during deposition.

As previously mentioned, anticlines as expressed on the "Corniferous" are shifted considerably from their surface or shallow subsurface positions. On north-south anticlines this shifting is apparently very slight, but on some northeast-southwest structures the axes migrate several miles, shifting toward the northwest. Anticlines that appear regular from surface and shallow subsurface mapping have been found, by the use of reflection-seismograph surveying, to be faulted and generally more complicated than the early work indicated. In this respect, it should be mentioned that the Facemeyer (No. 6 on Fig. 2) of the United Carbon Company, in the western part of the

Elk-Poca field, was the first commercial well in the state located solely on seismograph surveying. Reflection-seismograph surveying has provided a very valuable check on the structural attitude of the deeper horizons in West Virginia and should help materially in deep wildcat wells, especially in areas where water is thought to be present.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 2 (FEBRUARY, 1938), PP. 189-200, 6 FIGS.

PRACTICAL REPRESSURING[1]

NEWELL M. WILDER[2]
Lexington, Kentucky

ABSTRACT

This paper is intended for use as general information pertaining to the extraction of crude oil from partly depleted oil-bearing strata, by the use of compressed air and natural gas as repressuring mediums. Its scope is limited to various properties that are producing from the "Corniferous" formation of eastern Kentucky. The writer has attempted to avoid theoretical assumptions as far as possible so that the paper might be readable to those who are interested in the phases of actual operation. Operations of various individual projects are described in detail as to their histories from the beginning of repressuring to the present. Discussions relating to injection volumes and pressures with reference to core analyses are based on first-hand data.

INTRODUCTION

The problems of repressuring oil reservoirs to extract a part of the oil remaining therein are as varied as the natures of the reservoir rocks themselves, and sometimes even more so. It is our business to analyze and find out what these problems are and to what limits they extend. Information and data obtained from sand may correspond analytically with those of another or even with those of the same sand in different localities, and yet the difficulties in repressuring the sand are not necessarily solved in the same way; just as a working theory for an individual well may not fit another—even an adjacent—well.

A great deal of research has been conducted on various methods for extracting oil from the reservoir rocks and many theories relating to repressuring questions have been advanced. Much has been published on the results in relation to various air and gas injection projects. Still, the art of repressuring is considered as being in its infancy. One can not say to another what the amount of the injection fluid should be, or how fast it should be put in each well. Many questions pertaining to the practice of repressuring can not be answered satisfactorily. Conditions in the sand are so variable that no definite rules are set forth for particular phases of the work.

The writer does not attempt in this paper to formulate any rules to be used as standard, but rather to point out by discussion the complexities involved in such problems; also, to discuss various repressuring projects in Lee, Estill, and Powell counties, Kentucky, that are being successfully used on the "Corniferous" (Onondaga) formation.

[1] Read before the Association at the mid-year meeting, Pittsburgh, October 16. 1937. Manuscript received, October 7, 1937.

[2] Petroleum geologist, Petroleum Exploration.

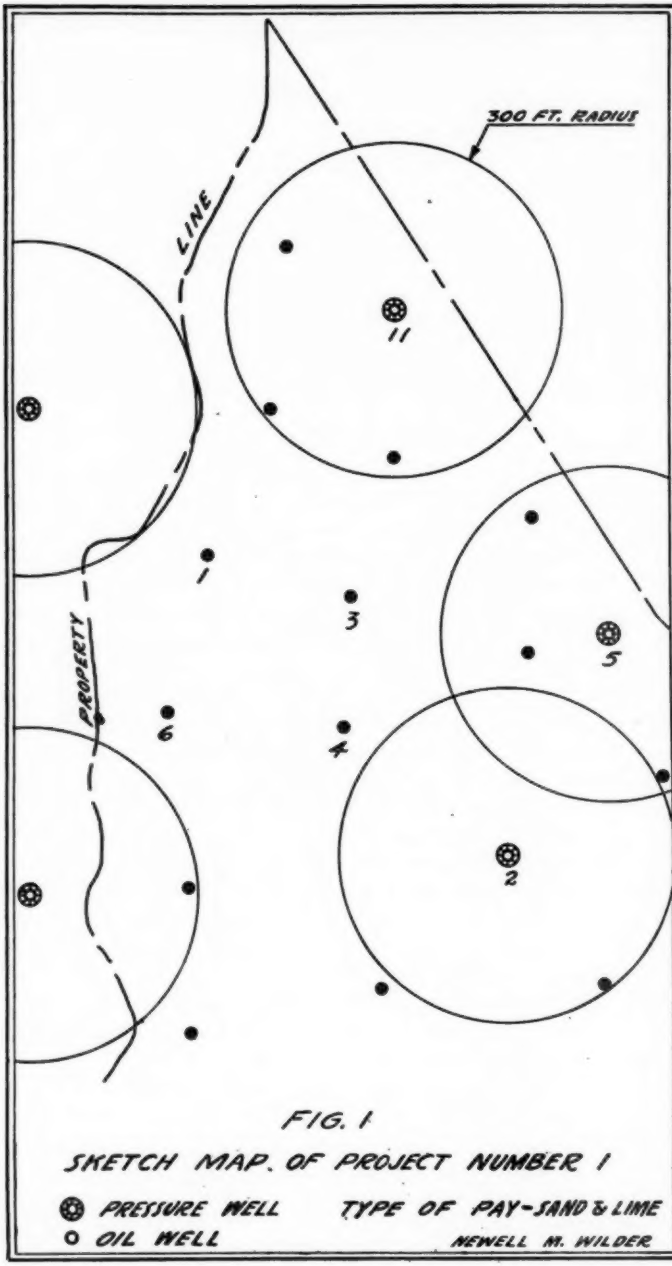

300 FT. RADIUS
PROPERTY LINE
11
1
3
5
6
4
2
FIG. 1
SKETCH MAP. OF PROJECT NUMBER 1
PRESSURE WELL
TYPE OF PAY-SAND & LIME
OIL WELL
NEWELL M. WILDER

Fig. 1

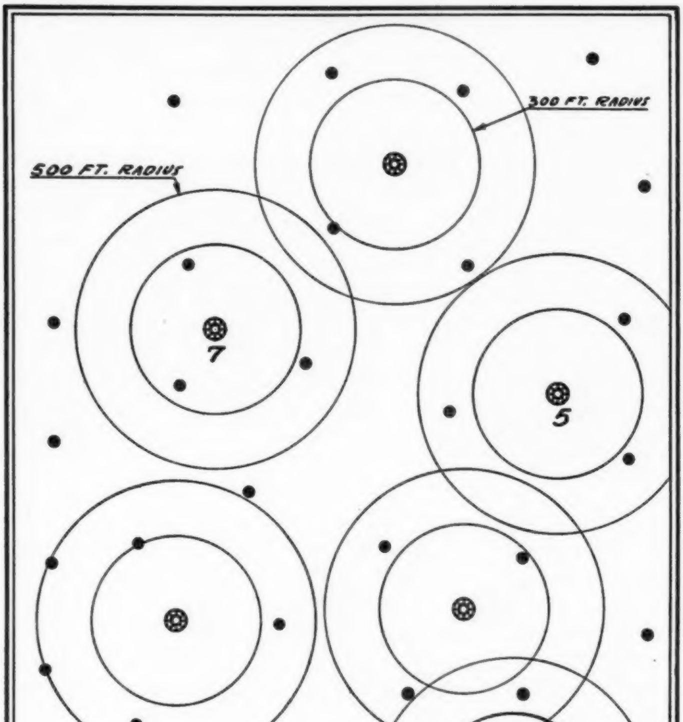

500 FT. RADIUS
300 FT. RADIUS
7
5
FIG. 2
SKETCH MAP OF PROJECT NUMBER 2
PRESSURE WELL
OIL WELL
TYPE OF PAY—
SAND WITH LIME STREAKS
NEWELL M. WILDER

Fig. 2

WELL SPACING—PATTERNS

The location and number of pressure wells depend largely on the spacing of the present pumping wells. Close spacing is advocated, usually 250–300 feet from pressure well to oil well. This may be impossible, however, because of the location of existing wells and conditions of topography. The size of the lease operation and the location of the boundary line may affect the laying out of a definite system of intake wells. In other words, a 5-spot, 7-spot, *et cetera*, pattern is not everywhere practical. Failure of adjoining lease owners to coöperate in repressuring line wells may work to the detriment of all operators concerned. Theoretically, the oil is not moved or dragged over any great distances. It may happen that a well several hundred feet from a pressure well shows an increase in production as a result of the air or gas volume being injected into the pressure well. This does not necessarily mean that oil has traveled the distance from the pressure well to the oil well, but, more likely, that the air or gas, having reached this point through the act of filling voids and going into solution with the oil, has expanded into the well, carrying oil with it from the immediate vicinity and some from as far back in the reservoir as the zone of marked differential pressure exists. Moreover, the writer has observed in the pulling of pressure wells for alterations *et cetera*, that oil in the near vicinity of the well immediately runs into it as the pressure is taken off. Accordingly, the closer the spacing the greater the recovery should be.

The commonly known systems of spacing in repressuring work are those in which the ratios of oil wells to intake wells are 8 to 3, 2 to 1, 1 to 1, *et cetera*. Generally, it has not been economically practical, in the writer's experience, to operate on the lower ratios where small leases are involved, as not all wells are affected by the repressuring medium. Figure 1, of project No. 1, shows the history of a lease that has been under pressure since 1934. Considering the edges of the adjoining coöperating leases, the ratio of oil wells to pressure wells here would be approximately 4 to 1. An old oil well, No. 2, is still a pressure well due to the fact that it is the original experimental well. Numbers 5 and 11 are cored wells and were placed so as to affect as many oil wells as possible and to serve as line wells. The arrangement approaches that of a 7-spot pattern, although the system is not complete over the whole lease. It is possible that a pressure well could be added to advantage between wells 1, 3, 4, and 6. The average distance from pressure wells to oil wells is approximately 300 feet.

A more complete arrangement of patterns is illustrated in Figure 2, of project 2, where a start has been made on a large lease. The

FIG. 3

FIG. 4

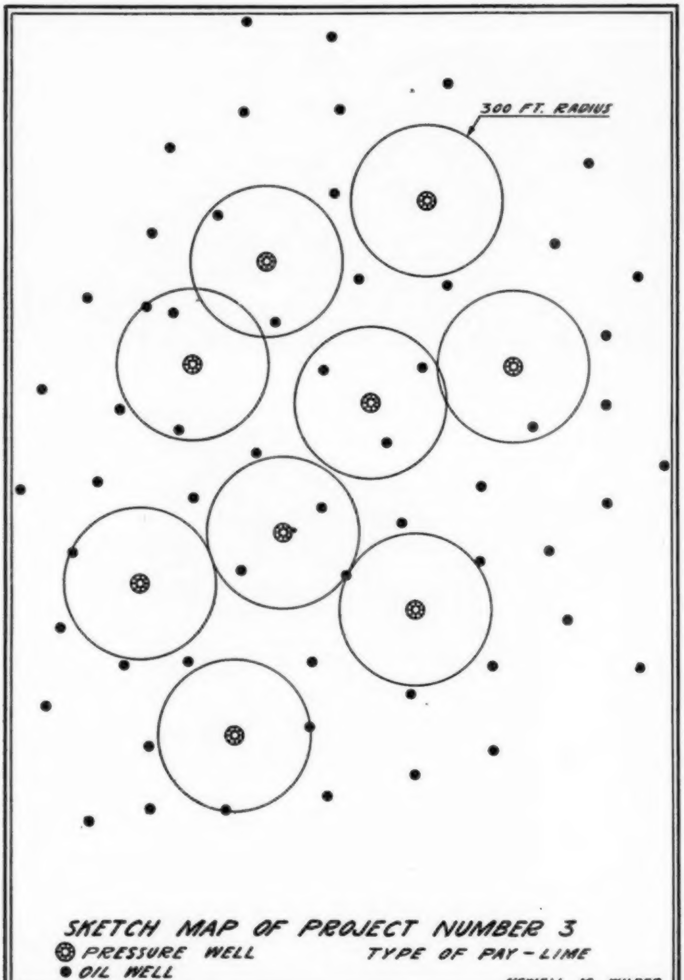

300 FT. RADIUS
SKETCH MAP OF PROJECT NUMBER 3
PRESSURE WELL
OIL WELL
TYPE OF PAY - LIME
NEWELL M. WILDER

FIG. 5

typical 5-spot is in evidence here, and although the spacing between pressure wells and oil wells is somewhat greater (370 feet, approximately) than that which is recommended, the results have been quite satisfactory. It is doubtful whether a closer spacing of pressure wells would have been economical, as the approximate depth to the "pay" is 1,000 feet and the topography is very rough (Fig. 3).

A much closer spacing arrangement of pressure wells is pictured in Figure 5, of project 3, where the distance is approximately 600 feet, as compared with that of Figure 2, where the average interval is nearly 900 feet. No definite pattern is in view here, although the pressure wells themselves are arranged systematically. Closer spacing is more practical because of lower drilling costs. The sand depth ranges from 150 to 380 feet.

The plan generally used for the spacing of groups of wells is that each pressure well be in a position to affect at least four oil wells and be approximately 300 feet from each, and not more than 900 feet from adjacent pressure wells.

PREPARATION OF PRESSURE WELLS

Each pressure well is cored and the core analyzed. All pressure wells are new wells and each is treated individually. The well is not shot or treated with acid. From the permeability profile of the analysis a study is made as to the possibility of zoning the sand into sections by the use of packers. The packers are placed according to the permeability, and to some extent, the saturation profile. Packers are placed at points where marked changes take place in the permeability or where it is desired to isolate sections of different permeable values. The number of packers in a well is determined by the number of zones necessary for the efficient operation of the well. It is necessary to take these steps or similar ones in order to feed air or gas to as much of the sand face as possible. Air or gas injected into an open well would tend to expand in the direction of lowest resistance—zone of highest permeability. This particular part of the sand may not necessarily be the highest saturated and may represent at best a comparatively small part of the entire pay thickness. It does not seem possible that energy in the form of compressed air or gas injected into an open well without regard to the characteristics of the rock comprising the reservoir could ever approach the stage of doing efficient work.

In some cores, particularly in limestone cores, it is difficult to obtain a satisfactory permeability profile. In dealing with such a situation, the cores of surrounding or adjoining pressure wells are taken into account when zoning the pay sand.

The oil content of a core has, to a certain extent, some relation to packer placements in so far as certain parts of the sand may be saturated, and certain parts may not be. The oil content of all cores mentioned in these projects has been determined by conservative analysis, and all that have shown oil were apparently rich enough to encourage a program of repressuring.

Figure 4 shows the manner in which the well-head connections are made. The lines carrying different pressures to the different zones are telescoped within each other, the smallest line reaching the bottom zone. Each line is equipped with regulator, orifice connections, check valve, and two stops. All materials placed in the well are of new stock, while some second-hand equipment is used to advantage on the surface.

INJECTION VOLUMES, PRESSURES, RESULTS

One of the most important problems concerned with repressuring work is that of volume and pressure. Questions often asked are: "How much air should be put in the wells?" "How much pressure is needed?" These can not be answered even generally. The sands are not consistent in their makeup as far as repressuring work is concerned. Ordinarily every lease and every field differs from every other. Of course, every different kind of rock would offer different possibilities, and different strategy, especially in the detail part of the work, would be required for the extraction of the oil. It is known that two different sands of the same average permeability will not necessarily take a volume of air or gas at the same pressure, even though the saturation factor is not materially different. In some instances it is surprising to note the difference in pressure required to realize the same purpose. An illustration of this is seen in the two lowest zones of the wells shown in Figure 6.

Experience gained from the projects mentioned in this paper reveals that each pressure well must be treated individually. The number of zones in wells of one project vary from one to four according to the nature of the sand; and so the thickness of "pay" exposed to the zones would be variable in most cases. For this reason it is easily seen why the several wells are not given the same total volume of air or gas. The injection fluid is directed to the sand of each zone on an average per foot basis.

Project 1, which was begun in January, 1934, with an old well, received an average of 25,000 cubic feet of gas daily with 45 pounds pressure for a period of 21 months. This amounted to 625 cubic feet per foot of "pay." The production was doubled. At this time another pressure well and two on the adjacent lease were added and the repressuring fluid was changed from gas to air. A third pressure well

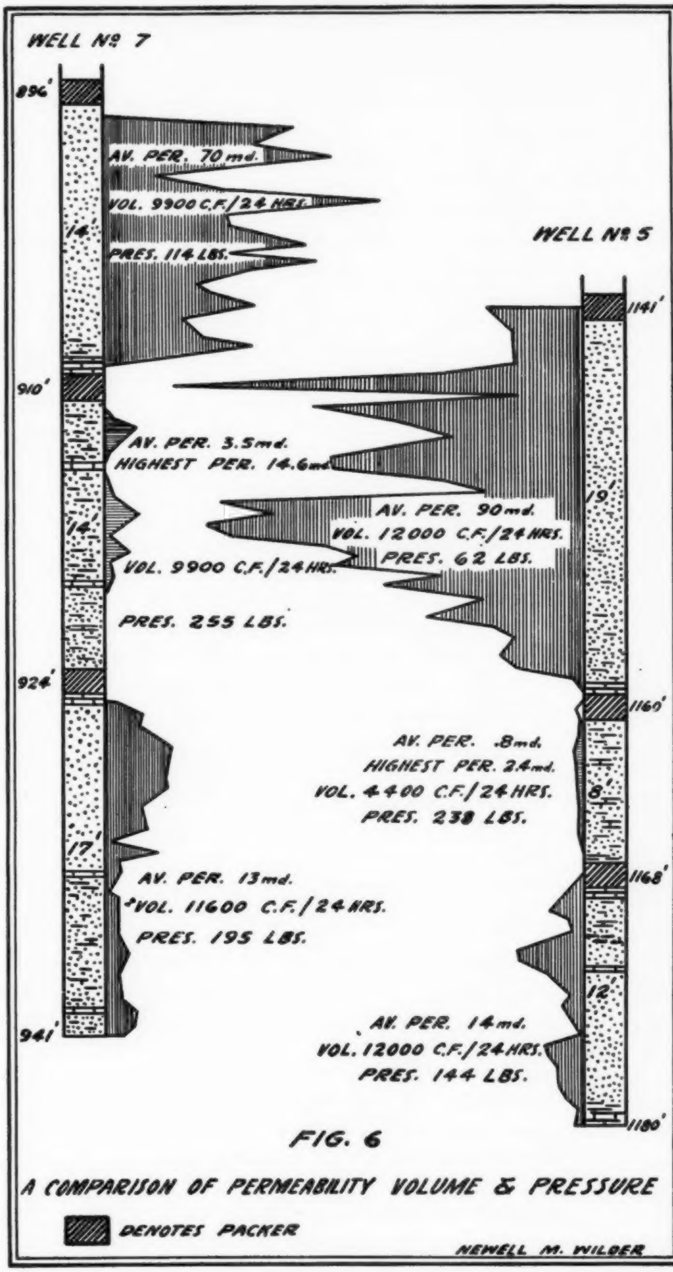

WELL Nº 7
896'
AV. PER. 70 md.
VOL. 9900 C.F./24 HRS.
14'
PRES. 114 LBS.
910'
AV. PER. 3.5 md.
HIGHEST PER. 14.6 md.
14'
VOL. 9900 C.F./24 HRS.
PRES. 255 LBS.
924'
17'
AV. PER. 13 md.
VOL. 11600 C.F./24 HRS.
PRES. 195 LBS.
941'
WELL Nº 5
1141'
19'
AV. PER. 90 md.
VOL. 12000 C.F./24 HRS.
PRES. 62 LBS.
1160'
AV. PER. .8 md.
HIGHEST PER. 2.4 md.
VOL. 4400 C.F./24 HRS.
PRES. 238 LBS.
8'
1168'
12'
AV. PER. 14 md.
VOL. 12000 C.F./24 HRS.
PRES. 144 LBS.
1180'
FIG. 6
A COMPARISON OF PERMEABILITY VOLUME & PRESSURE
DENOTES PACKER
NEWELL M. WILDER

FIG. 6

was added 3 months later. During the year 1936, the volume of air injected amounted to approximately 450 cubic feet per foot of pay sand. During 1937, the volume being injected is approximately 625 cubic feet per foot of "pay." This figure is not applicable to the sand of the less permeable zones, as line pressures are not sufficient. The pressures required for the above volume are from 55 pounds to 155 pounds, depending on the permeability and thickness of each zone. The increased production rate to the present time amounts to 533 per cent of the original. Table I shows actual production figures for this and other projects from the beginning of repressuring operations to October, 1937. The recovery per acre of cumulative oil, due to the effects of repressuring only, is, at the present time, 580 barrels. Likewise, the recovery per well is 2,071 barrels. Actually, these figures should be much higher, since only a part of the total acreage and wells of the lease are affected.

The history of project 2 dates from 1936. Like that of project 1, it is a sand with an occasional limestone "pay" in the top part. The rate of gas injection was low at first and was gradually increased until June, 1937, when the rate of 700–1,000 cubic feet per foot of "pay" was being used on a 24-hour basis. During this period of 17 months the production rate for the project was increased to 300 per cent, or from 42.2 barrels per day to 126.6 barrels per day. Individual wells showed increases of as much as 624 per cent, while others were only slightly affected.

TABLE I

PRODUCTION, IN BARRELS, OF THREE PROJECTS BEFORE AND AFTER REPRESSURING

Project Number	*Repressuring Period to October, 1937 (in Months)*	*Average Daily Production Prior to Repressuring*	*Present Daily Production*	*Total New Production Gained*
1. Sand and limestone	45	7.5	40	29,000
2. Sand with limestone streaks	20	42.2	107	20,290
3. Limestone	15	14.6	58.4	14,369

In June, 1937, the project was put on a 12-hour basis, due to a shortage of gas. The rate of injection remained the same, which means that the volume of gas per foot of "pay" amounted to 350–500 cubic feet for the 12-hour periods. In July the rate of injection was cut approximately one-third and the working barrels in some oil wells were raised above their previous levels to cut back some of the free gas. As a result of the changes made since June the production has dropped approximately 15 per cent, or 19 barrels per day. The cumulative gain in oil produced from this project during the past twenty-one months is more than 20,000 barrels.

The pressure wells of this project are very nearly consistent in their number of variable permeability zones. Figure 6 represents two wells with approximately the same analysis in regard to permeability. In well No. 7, the average permeability in the top is approximately 70 md. The average permeability in the middle is 3.5 md. The same total volume of 9,900 cubic feet of gas, or an average of 707 cubic feet per foot of "pay" is being injected in both zones which are equal in thickness (14 feet). The ratio of permeability of top to middle is 20 to 1. The pressure required on the top for 9,900 cubic feet of gas is 114 pounds. The pressure required on the middle is 255 pounds. The ratio of middle to top pressure is only 2.23 to 1.

In well No. 5, the average permeability of the top zone is 90 md. Average permeability of bottom is 14 md. This is in the ratio of 6.4 to 1. The volume being injected in each zone is 12,000 cubic feet per day and the pressures required for these are 62 pounds on top and 144 pounds on the bottom, a ratio between bottom and top of 2.3 to 1.

A comparison of pressures in the foregoing zones of wells 7 and 5 shows that they are in the same proportion (2.3 to 1), yet the reverse proportions of the permeabilities are not nearly the same (6.4 to 1, and 20 to 1). These comparisons may not seem to have any connection, and yet these inconsistencies seem to exist from one location to another, although not always in as great proportions. An interesting comparison is that between the two lowest zones of the wells in Figure 6: the permeabilities and the volumes of injected gas are nearly the same, numerically, while the pressure differential is 51 pounds.

Project 3 is that which is displayed in Figure 5, and is developed on the first of the three Corniferous "pays." The first "pay" of the Corniferous formation in this area is a magnesian limestone. Its pore space has been made possible by the dissolving action of acid waters. Some of the pores which range up to 3 inches in diameter are mineralized, the cavity filling being loosely cemented magnesium carbonate and possibly some sand. Other openings are hollow. In both cases the pores seem to contain oil. Due to the manner in which oil is confined in this "pay," it is not probable that as great a proportion of the core-analyzed oil would be recovered as would be in the sandy phase of the formation.

The project, like the others, has no vacuum pulling on the formation. All of the pressure wells were cored and put in operation. This was followed by a program of drilling new oil wells, during which 40 per cent of the wells shown were drilled.

The volume of air injected in the pressure wells at the beginning of this operation in 1936 was approximately 300 cubic feet per average

foot per 24 hours. This was not in excess of 7,000 cubic feet per well. The injection rate at the present time is 600–700 cubic feet per foot of "pay." The pressure range on the various zones is from 9 to 70 pounds.

The permeability profiles of cores in this "pay" are very irregular. It is not uncommon to see the curve alternating from high to low through almost every successive point in the length of a zone, and in places in the length of the core. For this reason it is not easy to assume a figure which would be representative of the average permeability.

The result of repressuring this property has been a steady increase in production. The effects from the injected fluid have not been general over the entire area. One part of the project including approximately 5/12 of the total area has a daily production of more than double its previous rate. The production of the other 7/12 has been increased more than six times, or actually, from 6.6 barrels per day to 41.4 barrels per day. The production for the project has been raised from 14.6 barrels per day to 58.4 barrels per day. During the past 15 months more than 14,000 barrels of new production have been gained. A contributing factor in the success of this property is that eagerness for quick recovery has not been a part of the program.

GAS-OIL RATIO

Gas-oil ratios of individual wells are important in repressuring work as an index to the progress of the operation. Many failures and much trouble can be eliminated by giving due regard to this phase of the work.

In the foregoing projects the gas-oil ratio of wells that are equipped with individual test tanks has been, with a few exceptions, less than 2,000 cubic feet of gas per barrel of oil. When the ratio begins to approach the 2,000 mark the volume of gas is cut back by methods of trial. The working barrel is sometimes raised to create a higher fluid level in the well, thus causing a back pressure to be maintained against the gas flow. Another method of retarding the gas flow is the reduction of intake gas in the highest permeable zones of pressure wells that seem to be the influencing factor.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 2 (FEBRUARY, 1938), PP. 201-216, 4 FIGS.

SEDIMENTS OF SANTA MONICA BAY, CALIFORNIA[1]

F. P. SHEPARD[2] AND G. A. MACDONALD[3]
La Jolla and Berkeley, California

ABSTRACT

The collection and analysis of sediments from Santa Monica Bay adds to the information concerning the continental shelves in that this bay represents a different environment from those previously investigated. The narrow shelf cut by the two submarine canyons, the sources of material from the flood waters which come out of the Santa Monica Mountains, and the good development of currents coming from the northwest make up these environmental influences.

The sediments of this shelf were found to show no particular outward decrease in grain size. Both coarse materials and rocky bottom were found near the outer margin as well as near shore. Evidence of periodic changes in the sediment character was found. It seems highly probable that the shelf is essentially a wave-cut terrace, that much of its sediment is residue from times of lower sea-level during the glacial stages, and that much of the modern sediment is of transitional character. There are some indications that oil may be accumulating in the finer sediments of the bay.

INTRODUCTION

Santa Monica Bay is in a broad indentation of the coast extending between Palos Verdes Hills on the south and Point Dume on the north, a distance of 35 miles. In this bay there is a relatively wide continental shelf in contrast to the condition along most of the coast of Southern California. A collection of approximately 200 sediment samples was made from this shelf and from the two submarine canyons which cut the shelf. A small pipe dredge was used for most of this work. Samples were obtained also from the local beaches for comparison. Mechanical analyses of 139 of these samples and heavy-mineral determinations of 27 of the samples were made by the junior writer. Analyses were obtained by the usual screening operations. The Wentworth grade scale was used[4] to determine the different grades of gravel, sand, silt, and clay. Since the 1/16 millimeter screen was thought to be of uncertain value, elutriation was employed to determine the amount of silt and clay. For 12 of the finest samples pipetting was employed to distinguish the amounts of the different grades of silt.

[1] Contributions from the Scripps Institution of Oceanography, New Series, No. 13. Manuscript received, September 7, 1937.

[2] The Scripps Institution of Oceanography and University of Illinois.

[3] The University of California.

[4] C. K. Wentworth, "A Scale of Grade and Class Terms for Clastic Sediments," *Jour. Geol.*, Vol. 30 (1922), pp. 377-92.

CHARACTER OF COAST

From Santa Monica down to Palos Verdes Hills the coast follows the outer edge of the Los Angeles plain (Fig. 1). Along most of this extent, low cliffs have been cut into the Quaternary alluvium which was built out from the various mountain ranges, but south of Venice there is a low swampy stretch of land where Ballona Creek enters the sea and where an estuary has been cut off by the building of a bar across its mouth. Around El Segundo and Manhattan Beach the land directly inside the coast owes its elevation in part to a ridge of sand dunes which continues to receive some supply of sand from the adjacent beaches. The straightness of this portion of the coast is remarkable not only because of the indication of former estuaries, but also because the structure of the Quaternary alluvium shows that there are three distinct anticlines cutting diagonally across the coastal trend.[5] Evidently the straightening influence of the waves has been effective in these unconsolidated materials in trimming off the ends of the rising anticlines which have given surface relief to the coastal plain inside. Few streams enter the sea in this area.

The northern end of the bay is bordered by the Santa Monica Mountains, a range which rises as much as 3,000 feet. Along this stretch many streams enter the ocean. The coast is somewhat irregular along the mountain front, having small projecting points and crescent-shaped indentations. The rock formations along this part of the coast are a mixture of Cretaceous and Tertiary sedimentary rocks of varying degrees of resistance. There are also some patches of volcanic rock.

South of Los Angeles Plain, Palos Verdes Hills rise to a height of 1,479 feet. These hills cause an outward projection of the coast which is probably to a large extent of tectonic origin as is shown by the well developed wave-cut terraces of Pleistocene age[6] which are so evident along the sides. The rocks in Palos Verdes Hills range from Franciscan (Jurassic?) up to Pleistocene, and consist mostly of sedimentary rock but with some patches of lava. The Miocene shales, however, make up the greatest part of the hills. Because of their small size and recent origin the hills do not have any well developed drainage system.

SUBMARINE TOPOGRAPHY

The general configuration of the sea bottom in Santa Monica Bay can be seen from an examination of Figure 1. This area is one of the few places south of Monterey Bay where there is an appreciable con-

[5] R. D. Reed and J. S. Hollister, *Structural Evolution of Southern California* (1936), Plate I.

[6] W. P. Woodring, "Fossils from the Marine Pleistocene Terraces of the San Pedro Hills, California." *Amer. Jour. Sci.*, Ser. 5, Vol. 29 (1935), pp. 292–305.

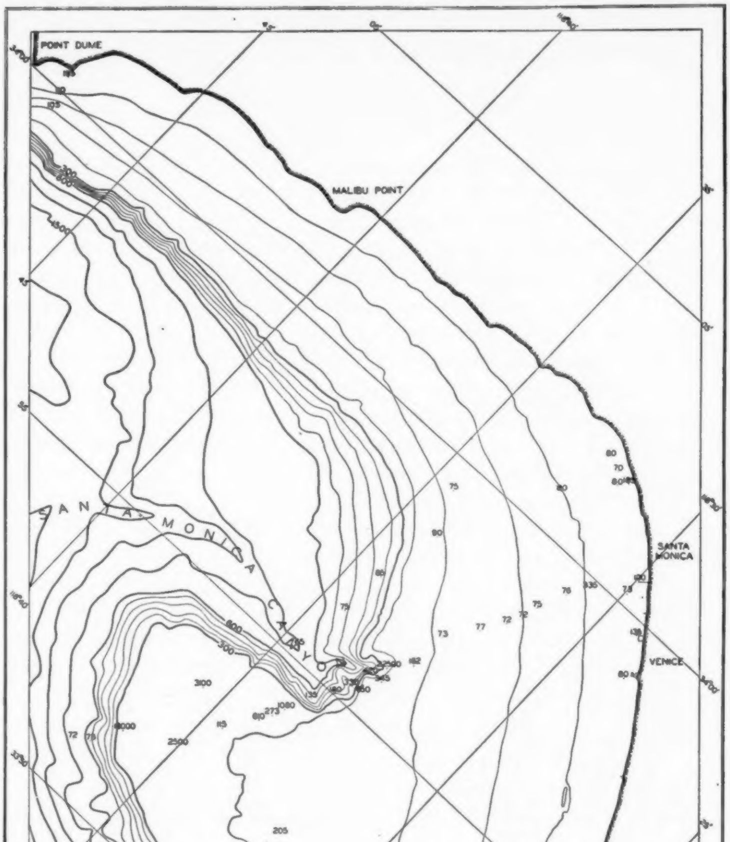


Fig. 1.—Bottom topography of Santa Monica Bay. Median diameters of analyzed sediments are given in microns so far as their distribution could be shown.

tinental shelf.[7] Except where two submarine canyons cut the shelf the 300-foot contour is found out about 10 miles from the coast. This depth of 300 feet represents the approximate outer boundary of the shelf. The shelf is comparatively flat, although there are some hills of small proportions rising above its surface.

The Redondo submarine canyon cuts across the shelf almost to the coast. There can be little doubt that it has an appreciable effect on the migration of the sediment along this shelf. The Santa Monica submarine canyon on the north does not penetrate the shelf as deeply, but it probably has had a marked effect on the sediments. It will be observed that the slope leading down to both canyons is less precipitous on the north than on the south side. The bottoms of the two canyons appear to slope outward continuously.

Beyond the 300-foot depth the slope increases and extends down to depths that are more than 2,000 feet where the bottom flattens. This slope, which is a miniature continental slope, has the straightness of a fault scarp. It is notable that its southward continuation practically follows the coast off Palos Verdes Hills and that the outward bend of the shore produced by the hills is not reflected in this apparent fault scarp.

BOTTOM DEPOSITS

The types of bottom in Santa Monica Bay are indicated in two ways. 1. A generalized sediment map (Fig. 2) gives the interpretation of the bottom which was made through a combination of the study of the samples which were collected and the bottom indications reported by the Coast and Geodetic Survey from their charting operations. Information obtained from fishermen was used also to a moderate extent in constructing the map (Fig. 2). The contour map (Fig. 1) gives the median diameter of each sample analyzed.

Rocky bottom.—It will be observed that a large part of the bottom is indicated as being rocky. This does not mean that these zones are quite devoid of sediment, but that rocks are found in these areas either as ledge rock or as loose pieces lying on the surface. The information regarding this rocky bottom comes partly from dredging operations which yielded angular fragments of shale and conglomerate which indicated that the material had not been carried across the shelf. It comes also from reports from fishermen who claim that they obtain certain types of fish only where the bottom is rocky and who find confirmational evidence of rock through the catching of their

[7] This use of the term *shelf* differs from that of Lawson ("The Continental Shelf off the Coast of California," *Nat. Res. Council Bull.*, Vol. IV (1934), Pt. 2, No. 44), but it follows the usual practice of geologists in referring to a flat shallow-water zone.

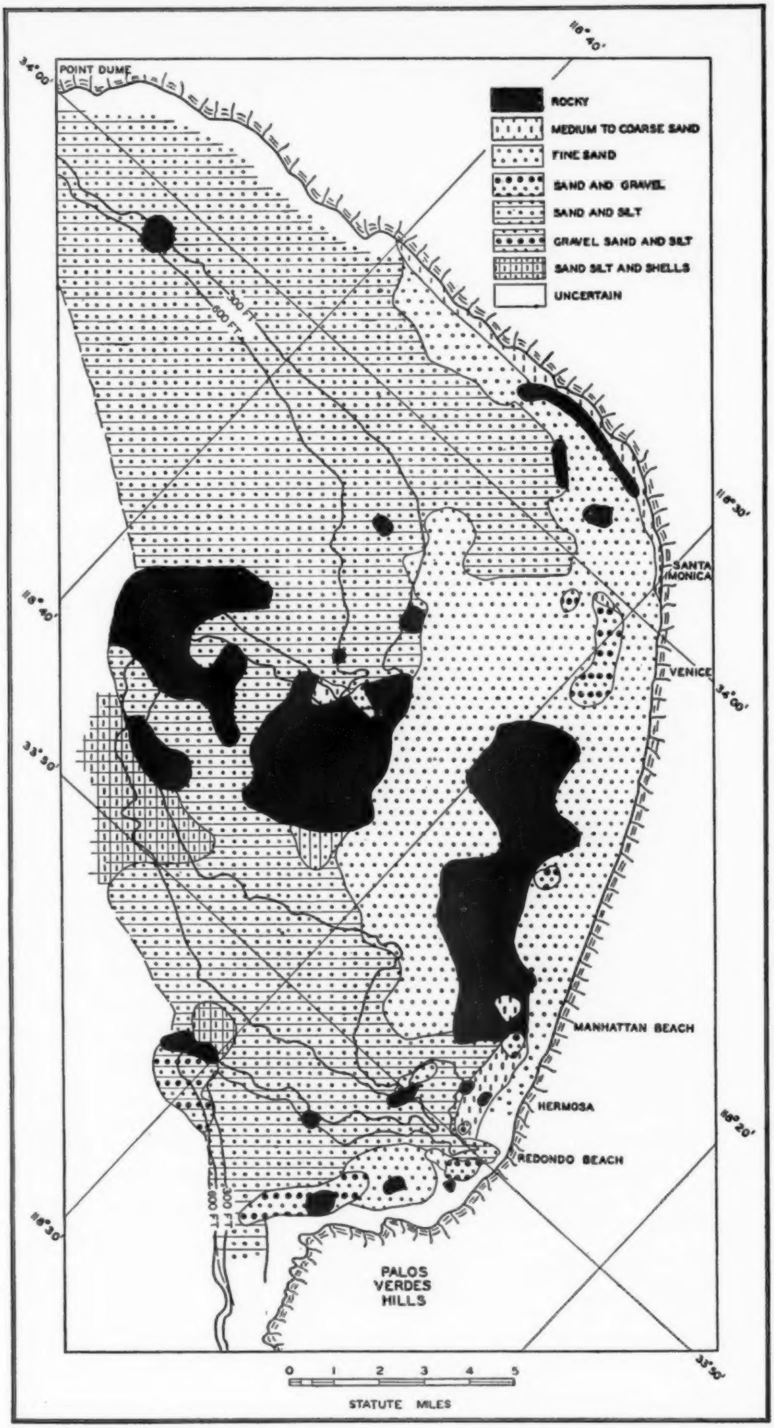


FIG. 2.—Distribution of types of bottom in Santa Monica Bay. Based on a compilation of sediments examined and of data from the Coast and Geodetic Survey and from local fishermen.

nets and hooks in the rocky bottom. Cobbles and boulders often tangle with their hooks because of the branching coral *Gorgonia* which grows on the rocks. The Coast and Geodetic Survey records also show rocky bottom either where the lead was scratched by rock or where the tallow in the bottom of the lead came up with angular pieces of rock. The observed indications of rock are found clustered in certain localities, making it highly probable that they do not represent sporadic fragments dropped by "holdfasts" or carried out by other means from the coast.

A number of the dredgings on the shelf south of Santa Monica Canyon brought up a shale which closely resembled the Miocene Modelo formation of the Santa Monica Mountains. Around Redondo Canyon many boulders are brought up by fishermen which probably come from some Pliocene or Pleistocene conglomerate.

RELATION OF GRAIN SIZE TO DEPTH

In previous papers the senior writer has called attention to the lack of any general decrease in grain size on the continental shelves as depth and distance from shore increased.[8] It might be supposed, however, that in the case of Santa Monica Bay the narrow shelf combined with the good supply of sediment from streams on the north would have permitted the sorting of the sediments to follow the theoretical arrangement, namely, coarse material near shore and fine farther out. It is interesting, then, to observe that no such ideal arrangement of sediments has developed. The direct relation between depth and coarseness can be seen in Figure 3*A*, where the median diameters for the different depth zones are plotted in a curve and compared with the straight line for increase in depth. Another comparison (Fig. 3*B*) shows how the grade sizes vary in going out from the coast off Santa Monica. In both cases it will be seen that the samples well out from the coast are on the average slightly finer-grained than those close to shore, but the change is by no means progressive. The abundance of gravel well out on the shelf causes the largest discrepancy from the theoretical arrangement in these results, but neglecting the gravel, there is sufficient coarse sand in the samples outside to show that the rule does not operate.

Of the samples analyzed, the coarsest, with a median of 22,500 microns, came from 36.8 fathoms at the head of Santa Monica Can-

[8] F. P. Shepard, "Sediments of the Continental Shelves," *Bull. Geol. Soc. America*, Vol. 43 (1932), pp. 1017–40.
F. P. Shepard and G. V. Cohee, "Continental Shelf Sediments off the Mid-Atlantic States," *Bull. Geol. Soc. America*, Vol. 47 (1936), pp. 441–58.
F. P. Shepard and W. F. Wrath, "Marine Sediments around Catalina Island," *Jour. Sed. Petrology*, Vol. 7 (1937), pp. 41–50.

yon 5 miles from shore; the finest, with a median of 20 microns, came from 31.5 fathoms on the flat shelf 4 miles off El Segundo.

Relation to submarine canyons.—There is little doubt that the canyons have had some influence on sediment distribution. The contrast between the type of deposit on the north side of the Santa

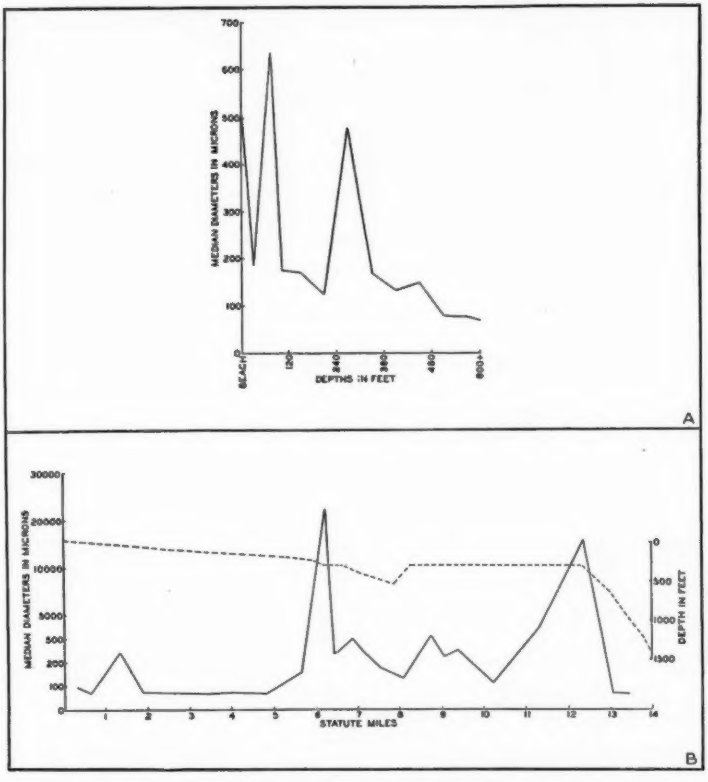


FIG. 3.—*A*. Diagram showing the comparison of median diameters with depth zones. *B*. Profile of bottom extending out from Santa Monica across head of Santa Monica Canyon to edge of shelf, compared with median diameters of sediments collected along this line. Broken line shows profile, and solid line shows medians. Vertical in profile ×10.

Monica Canyon and that on the south is too striking to be coincidental. It appears that fine sediment is very scarce on the south side and that it is essentially a rocky bottom with gravel and coarse sand, while on the north side only sand and silt are found, except in

one place. The contrast is not as striking in the case of Redondo Canyon, but the same general difference may be observed. The sediment in the bottom of the canyons is for the most part finer than that on the adjacent parts of the shelf. Even in these canyons, how-

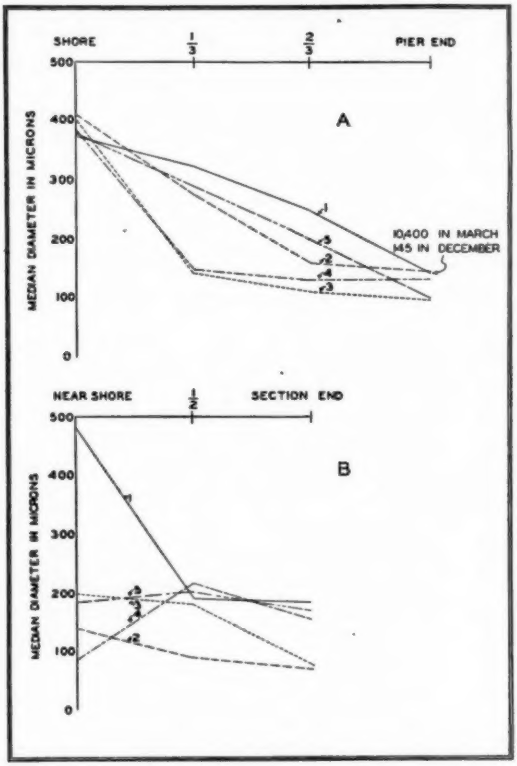


FIG. 4.—*A*. Diagram showing variation in median diameters of sediments taken along the length of several piers. Depths range from 0 to 25 feet. *B*. Lines similar to those in *A*, but taken from rowboats starting just outside the breakers and extending to about 25-foot depths.

ever, there is a considerable amount of sand, not less than 37 per cent of any sample.

Relation to shelf margin.—One of the coarsest samples was discovered at the outer margin of the shelf south of Santa Monica Canyon. Also the graph shows that the sediment in general is coarse at

depths ranging from 40 to 50 fathoms, representing the outer edge of the shelf in this area.

Near-shore zones.—If the sediments do not grade outward into finer and finer material across the shelf they might at least be supposed to show such gradation near the shore. Several tests were made for the purpose of determining the truth or falsity of this supposition. Samples were taken along the length of 5 of the piers and also, by using a rowboat, samples were obtained along lines running out from the coast west of Santa Monica. These lines began either at the beach or just beyond the breakers and extended about 1,000 feet. The outer depths along these lines averaged about 4 fathoms, which is obviously well within the range of wave activity, particularly during storms. The results of analysis of grain size of these samples is indicated in Figure 4. It will be observed that in general the grain size does vary with the depth, the coarsest being found on shore. However, there are several exceptions even in this shoal water. At the end of the Hermosa Pier extremely coarse material was found at one time of the year and fine material at another. Also in some of the sections off the Santa Monica Mountains a zone of rocky bottom was discovered at a short distance from shore.

Perhaps the most significant feature of these near-shore sections is the fact that within a few hundred feet from shore, and in depths of a few fathoms, sediment is found which on the average is just as fine as that far out on the shelf.

The strange thing about this rapid decrease in grain size is that in most places just beyond the zone of fine sediment there is a zone of very coarse material (Fig. 3).

SORTING OF SEDIMENT

In general the sediments are well sorted. The sorting is certainly more pronounced than that observed in studies of east coast sediments.[9] Two of the samples have as high as 90 per cent of their total material in one grade size and four others have more than 80 per cent in one size. The best sorting is found in general near the shore, four samples of the six mentioned being found in water of less than 5 fathoms depth. However, good sorting was found in some of the deeper samples, as in sediment collected from 22 fathoms outside Santa Monica, which has 88 per cent in the very fine sand grade. Curiously enough the poorest sorting was exhibited by a sample taken in 42 fathoms of water a few miles farther out from Santa Monica, which shows only 18.3 per cent in its maximum grade size.

[9] F. P. Shepard and G. F. Cohee, *op. cit.*

Sixty-seven of the 139 analyses show maxima falling in the very fine sand grade. Next comes the fine sand grade in which there are 37 maxima, then medium sand with 17, then pebble gravel with 6, then very coarse sand with 5, and granule gravel and coarse sand with 2 each.

Secondary maxima were shown in 27 of the samples. Of these 15 show the secondary maximum in coarser material than the maximum, while 12 show the reverse relationship. The largest number of secondary maxima lie in the pebble gravel grade. East coast continental-shelf sediments show a considerably larger percentage with secondary maxima.

MINERAL CONTENT

The study of the mineral grains in the sands showed that quartz is the most abundant constituent. All of the samples had the additional light minerals, orthoclase and intermediate plagioclase, while most of them had small quantities of microcline. Rock fragments are also fairly common constituents and consist largely of black slate, chert, and fine-grained quartzite.

The distribution of glauconite agrees essentially with that determined by Galliher for the sediments of Monterey Bay.[10] It is lacking in the beach sands, and is rare or absent in samples from depths of less than 3 fathoms. It becomes more abundant with increasing depth. In this connection it should be noted that the ratio of green to brown biotite also becomes greater with depth.

The heavy minerals identified include: magnetite, ilmenite, garnet, green hornblende, hypersthene, brown and green biotite, epidote, purplish (probably titaniferous) augite, diopside, chlorite, glaucophane, titanite, apatite, calcite, zircon, rutile, basaltic hornblende, zoisite, brown tourmaline, and andalusite. The relative abundance of the minerals is given in Table I. The mineral assemblage is about the same in all parts of the region, and indicates derivation from a mixed source, probably partly or even largely by reworking of the older sedimentary rocks of the surrounding region. The augite and hypersthene may have been derived from the basaltic lavas which are abundant in the western part of the Santa Monica Mountains. Glaucophane is characteristic of the metamorphic terranes of the Franciscan group in the California Coast Ranges, and indicates derivation either directly or indirectly from a Franciscan source. A possible source of such debris is from the small area of Franciscan rocks exposed in the central part of the Palos Verdes Hills, although it should be pointed out that glaucophane is present in more than usual abundance in a

[10] E. W. Galliher, *Bull. Geol. Soc. Amer.*, Vol. 46 (1935), pp. 1351–66.

sample from near Point Dume, at the extreme northwestern part of the bay. It seems more probable that the glaucophane, which is nowhere abundant, represents material reworked from older sedimentary rocks.

TABLE I

MINERAL GRAIN STUDIES OF SANTA MONICA BAY SEDIMENTS

Mineral	*Very Abundant*	*Moderately Abundant*	*Somewhat Rare*	*Rare*
Apatite		17	8	1
Andalusite				1
Purplish augite		9	13	3
Biotite		18	3	1
Chlorite		2	6	4
Diopside		21	3	
Epidote		22	4	
Pink to colorless garnet		22	4	1
Glauconite	1	3	7	4
Glaucophane		2	3	13
Hornblende	2	24	1	
Hypersthene		21	5	1
Ilmenite	2	24	1	
Magnetite		11	15	1
Rutile				4
Titanite		22	2	1
Brown tourmaline				3
Zircon		16	6	1
Zoisite			2	

Very little information is available concerning the heavy mineral assemblage in the older sediments of the region surrounding Santa Monica Bay. The list published by Cogen[11] for the Modelo formation of the Santa Monica Mountains does not include many of the minerals present in the Recent sediments. The additional minerals may, however, be present in some of the other stratified rocks of the region; moreover, it should be pointed out that Cogen's work covers only a small area of the Modelo. Also in view of the considerable lateral variation which he has demonstrated in the small area studied, it might be expected that additional minerals might be present in other parts of the formation. Still another possible source, especially of the abundant ilmenite and some of the basic ferromagnesian minerals, lies in the complex of crystalline rocks in the western part of the San Gabriel Range.

The abundance of apatite in these sediments, as compared with its greater rarity in most studied grain assemblages of older geologic age, is probably to be attributed at least in part to loss of the apatite in the older sediments during acid treatment.[12] In the present study, no acid treatment was found necessary.

[11] W. M. Cogen, "Heavy Mineral Zones in the Modelo Formation," *Jour. Sed. Pet.*, Vol. 6 (1936), pp. 3–15.

[12] H. B. Milner, *Sedimentary Petrography*, 2nd ed. (1929), p. 131.

The mineral grains constituting the sediments are for the most part angular to subangular in shape. Only a few are subrounded. In only one case did some of the grains show a moderate degree of frosting of the surfaces, suggestive of wind action.

CHANGING OF BOTTOM CHARACTER

Fishermen who operate on the shelf in Santa Monica Bay have informed the writers of shifting bottom conditions which they observed. Much of the fishing in this region is carried on in areas of rocky bottom. The report is that after heavy storms mud deposits form over portions of this rocky floor so that the fish disappear. Later on the rock bottom is said to become reëxposed. Of course these stories need some verification, but this would seem to be quite possibly true.

Some confirmation of stories of shifting bottom comes from the observation by the writer that the bottom at the end of the Hermosa pier had undergone a change between December 16, 1933, when gravel was found, and March 17, 1934, when a sample of fine sand was obtained. The change in median diameter of these two is from 10,400 microns down to 145. In this period there had been a considerable number of winter storms. Another similar case was found at the end of the pier off El Segundo where very poor samples of coarse sand and gravel were obtained on December 16 and fine sand with a median of 99 microns was obtained on March 10.

STRATIFICATION

No evidence is available regarding the stratification of the sediments except near the coast off Santa Monica. Here in connection with the building of the breakwater the city engineers made 25 cores at a distance from shore of approximately 2,000 feet and in water about 25 feet deep. These cores penetrated into the bottom from 22 to 55 feet. They all show stratification. At the top of these cores there is a layer which is labelled by the engineers as stiff clay with fine sand associated in most cases. Judging from an analysis of a near-by sample this material is probably a mixture of very fine sand and silt which would harden when dried. This layer varies in thickness from 3 to 12 feet, apparently becoming finer toward the bottom. Below is a layer of sand of variable thickness and coarseness. Other alternations are seen in the deeper cores. Two of the cores have gravel beds at some appreciable depth. The layers are somewhat lens-shaped, but presumably this would be shown more strikingly if the cores covered a more extensive area.

PETROLEUM IN SEDIMENTS

In crossing the branch of the Redondo submarine canyon, which extends north near its head, globules of oil were observed rising to the surface and forming films on the water. Sediment collected in the vicinity also shows traces of oil. Presumably the source of this oil is in beds beneath the surface similar to those which are a source on the adjacent land.

Examination of the sediment in general showed that organic matter was much more abundant in the samples of very fine sand and silt than in the coarser samples. These fine sediments yielded a strong "cut" when exposed to the action of organic solvents such as acetone or ether, which resembled very closely that given by a medium gravity crude oil from the Santa Barbara district. On evaporation of this extract a waxy residue was derived which was very similar to that yielded by the evaporation of the cut from the petroleum. Trask, however, found that such residues derived from modern sediments lacked any liquid fraction, indicating the absence of any true petroleum.[13] Thus the bituminous matter in the sediments from this area may not be true petroleum.

INTERPRETATIONS

Sources of coarse sediment on outer shelf.—The fact that there is much coarse sediment well out on the shelf and the association of this coarse material with rock bottom lead one to suspect that much of the sediment on the shelf was not supplied from the present coast. The rapid decrease in grain size observed in the short distances investigated out from shore confirms this supposition. Thus it would appear that the coarse sediment is either derived locally from the rock outcrops on the bottom or was carried out to its present position during a time of lower stand of the sea. Probably the latter interpretation is correct, as it would appear unlikely that gravels could be transported to any extent at depths of 50 fathoms or more, particularly in a relatively sheltered area such as Santa Monica Bay. A tentative assignment of this coarse material to the last glacial stage of lowered sea-level can be made.

Wave erosion as a source.—There are wave-cut cliffs along much of the coast of Santa Monica Bay, indicating that sediments have been derived from wave erosion along the shore. However, this is not an important source at the present time, as there is much evi-

[13] P. D. Trask, "Does Petroleum Form in Sediments at Time of Deposition?" *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14 (1930), pp. 1451–63.

dence that these cliffs have not shown any notable retreat during the past 30 or 40 years.

Rivers as a source.—Although the streams coming into Santa Monica Bay are ordinarily of negligible size, during the winter floods they become raging torrents and carry enormous quantities of sediment into the bay. The fact that they enter the open bay instead of coming into estuaries means that the sediment is carried directly into the sphere of waves and currents so that it becomes available for transportation across the shelf. After a flood it is found that the water is muddy for miles out from the coast; hence undoubtedly some sediment is carried across the shelf. However, the fact that there are peculiar anomalies of coarse sediment on the outer and on the intermediate portions of the shelf shows that most of the fine sediment is kept moving and presumably is deposited out in the deep basin beyond the shelf. There is certainly a considerable load of coarse sediment brought in during the floods, as can be seen by the delta accumulations which are left at the mouths of the various streams after the floods subside. Also samples taken from the streams show the enormous amount of sand which is being introduced. However, sampling after these floods has shown that the sand and gravel do not extend far out to sea. In fact, it was after the winter floods that the fine sediment was found to have covered the coarse material at the ends of the Hermosa and Hyperion piers. The coarser grades are evidently deposited along the shore and gradually distributed, causing the building up of the beaches.[14] Ultimately a considerable part probably goes to form the dune sands which are blown in from the beaches at El Segundo and Manhattan.

Effect of currents.—It has been shown that after the winter storms fine sediment is washed out to an appreciable distance from the shore—perhaps all the way across the shelf. We are confronted therefore with the problem of explaining the absence of a general cover of fine sediment on the outer shelf despite the apparent ability of storm waves to supply this sediment. It seems probable that the fine material is removed during periods of good weather. This is borne out both by the observation of the fishermen in regard to the mud covering the rocky fishing ground and by the finding of coarse sediment at the pier heads after a long period of good weather. It is during this good weather, particularly in summer, that the sand is drifted along the coast, building up the beaches. Probably the longshore winds cause a strong drift of the current from west to east or southeast

[14] U. S. Grant and F. P. Shepard, "Changes along the California Coast," abstract, *Geol. Soc. of America Proc. 1936*, pp. 75–76.

which is augmented by the flood tide. Out in the bay a set in this direction is observable during flood tide even when there is no wind. It seems likely that this current causes the removal of the fine sediment from a considerable portion of the floor of the bay.

One test of this idea of the effect of currents comes from the relation of the sediments to the submarine canyons. If the currents are carrying the mud toward the east and southeast they would tend to dump it into the canyons and, emerging on the leeward side, they should be relatively free of sediment and thus capable of keeping the leeward side swept clean of fine debris. This is just what was found (Fig. 2), particularly in the areas bordering Santa Monica Canyon.

Another effect of currents is observed at the break in slope at the edge of the shelf. The coarse sediment and rock bottom here are explicable by the higher velocity of the currents at the edge of the slope. The same phenomenon has been observed in many other places. It is particularly striking around Catalina Island.[15]

A wave-cut rather than a wave-built shelf.—The conception of a continental shelf being a combination of a wave-cut and a wave-built terrace will probably continue to occupy a prominent place in geology textbooks for some time to come. However, here in Santa Monica Bay we have one of the many indications that the wave-built portion of the shelf is lacking. The finding of rock bottom over so much of the outer shelf and particularly along the sides of the submarine canyons shows that any building out of the shelf by sediment must be of very minor importance, at least in this area. Further indication of the same point comes from the straight outer edge of the shelf which is in direct continuity with the steep slope off the Palos Verdes Hills. This steep slope has the topographic character of a fault scarp. Evidently one must conclude that the removal of sediment due to the cutting of the shelf in Santa Monica Bay resulted in this sediment being carried down the slope into the deep basin beyond, or perhaps to some extent being carried on shore to form beaches and sand dunes.

ACKNOWLEDGMENTS

The writers are indebted to Frank Hutton of Los Angeles and to B. M. Varney, of the University of California at Los Angeles, for their kindness in loaning the yachts, *Confidence* and *Queequeg*, respectively, for use in this work. Also some of the collections were made through the coöperation of the Engineering Department and the Department of Public Playgrounds of the City of Los Angeles.

[15] F. P. Shepard and W. F. Wrath, *op. cit.*

The help of C. P. L. Nicholls was particularly appreciated. Others who helped in connection with the analyses included Frank Tolman of the Richfield Oil Company and George Cohee of the University of Illinois.

DISCUSSION

R. G. REESE, Los Angeles, California (discussion received, October 6, 1937): The seepages off Redondo Beach, discussed by Dr. Shepard, might be more graphically described to a petroleum geologist as being off the Torrance oil field. This field, discovered in 1922, has been developed along the crest of the fold to a point about 4,500 feet inland from the coast line. Further development is restricted by law due to the presence of the city of Redondo Beach. Development to date has revealed an anticlinal nose, plunging at an approximate 2° angle in a general S. 65° E. direction. The projection of the axis westward beyond the developed area and into the ocean is nearly parallel with, and about 800 feet north of, a line connecting the seepages. The structure is believed to continue rising oceanward but not at a sufficiently high angle to expose the main oil zone in the vicinity of the seepages. Oil and gas showings, not of commercial importance, have been logged, however, at depths as shallow as 600 feet below sea-level within the developed area. The presence of these seepages in the ocean suggests that the strata in which these shallow showings have been observed crop out on the ocean floor and are the source of the oil and gas seepages discussed by Dr. Shepard.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 2 (FEBRUARY, 1938), PP. 217-221, 3 PLATES

GEOLOGICAL NOTES

ARAGONITE IN TEXAS AND LOUISIANA SALT-DOME CAP ROCKS[1]

Aragonite appears to be a rare mineral in the cap rocks of Gulf Coastal salt domes. The only reference to this mineral to date, so far as the writers can find, is a single occurrence at Stark Dome, Calcasieu Parish, Louisiana.[2] Since that discovery aragonite has been found in three other domes, in Texas: Palangana, Duval County; Orchard, Fort Bend County; and Clemens, Brazoria County.

In all these domes the aragonite occurs in the calcitic zone of the cap rock and in all there is some sulphur mineralization. Where found the including rock is ordinarily porous. Gypsum and anhydrite streaks are present in the calcitic zone of some of the discovery wells, and in one well at Clemens dome, where aragonite is especially prevalent, this mineral was found both above and below a 3-foot gypsum band, but in porous calcite and limestone.

Most of the occurrences are in the form of transparent, pseudohexagonal crystals ranging from 0.1 inch to 1 inch across. One of the crystals from Stark dome (Pl. 1, Fig. 2), is 2 inches across, is nearly opaque, and has a tannish color. About a foot of massive aragonite was cored in one well at Orchard. This is very faintly tannish in color and has a somewhat coarsely fibrous, parallel structure (Pl. 2, Fig. 2).

In order of deposition all the aragonite appears to be later than the main body of the calcite and calcitic rock closely associated with it.

The writers are indebted to B. P. Boehm, of the Texas Gulf Sulphur Company, and Harvey A. Wilson, of the Jefferson Lake Oil Company, for their interest and assistance in saving some of the core samples pictured.

Marcus A. Hanna, chief paleontologist
Gulf Oil Corporation

Albert G. Wolf, mining engineer
Texas Gulf Sulphur Company

Houston, Texas
January 12, 1938

[1] Published with permission of the Gulf Oil Corporation and the Texas Gulf Sulphur Company.

[2] Marcus A. Hanna and Albert G. Wolf, "Texas and Louisiana Salt-Dome Cap-Rock Minerals," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 2 (February, 1934), pp. 212–15.

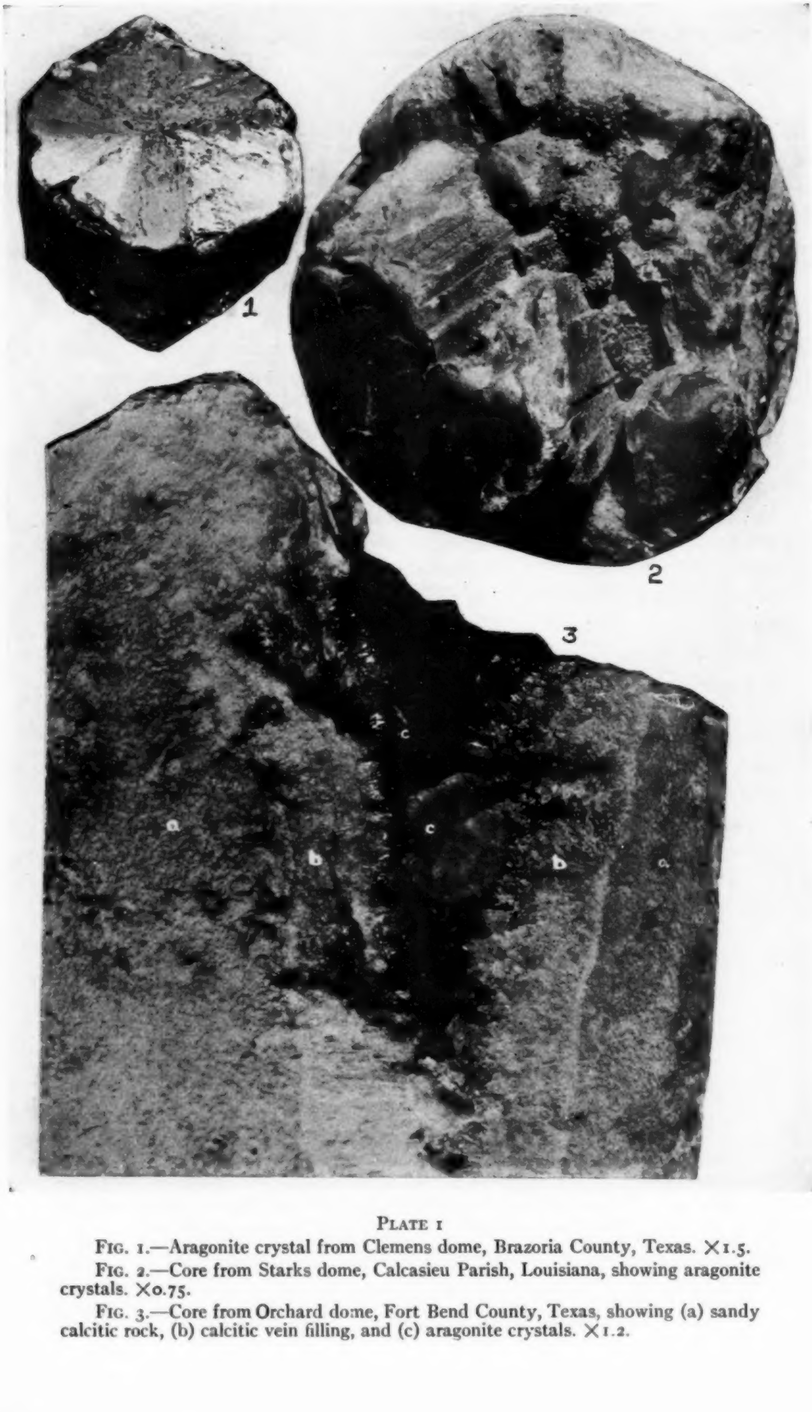


PLATE 1

FIG. 1.—Aragonite crystal from Clemens dome, Brazoria County, Texas. ×1.5.

FIG. 2.—Core from Starks dome, Calcasieu Parish, Louisiana, showing aragonite crystals. ×0.75.

FIG. 3.—Core from Orchard dome, Fort Bend County, Texas, showing (a) sandy calcitic rock, (b) calcitic vein filling, and (c) aragonite crystals. ×1.2.

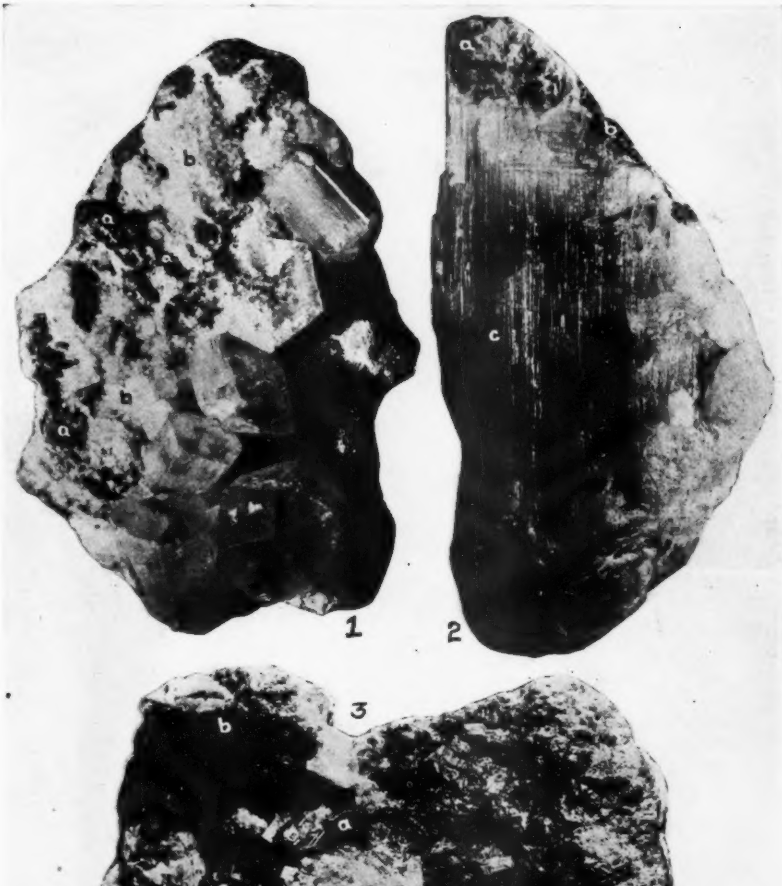


PLATE 2

FIG. 1.—Core from Clemens dome, Brazoria County, Texas, showing aragonite crystals, (a) sulphur, and (b) calcite. ×1.0.

FIG. 2.—Core from Orchard dome, Fort Bend County, Texas, showing (a) calcite, (b) sulphur, and (c) aragonite. ×1.0.

FIG. 3.—Core from Palangana dome, Duval County, Texas, showing (a) sulphur crystals, (b) calcite, and clear aragonite crystals near the center of the figure. ×1.0.

PLATE 3

FIG. 1.—Core from Clemens dome, Brazoria County, Texas, showing aragonite crystals, (a) sulphur, and (b) calcitic rock. ×0.75.

FIG. 2.—Core from Orchard dome, Fort Bend County, Texas, showing (a) aragonite, (b) sulphur, and (c) calcitic rock. ×0.9.

TRANSCENDENT VALUE OF GRAPTOLITES FOR CORRELATION DEMONSTRATED

The transcendent value of graptolites for correlation has been demonstrated in two articles received recently on faunas of southwestern and northwestern China. In the faunas from the southwestern region, Yin and Lu[1] list a large number of invertebrates. Among these the graptolites are particularly well represented, especially in the Silurian where the species are so well developed that correlation can be made for parts of the formation with four different divisions of the Silurian of Great Britain, namely, Lower Valentian, Upper Valentian, Wenlock, and Ludlow. In noting the presence of rich faunas of other invertebrates in the Ordovician, it is stated: (p. 37) "By good chance graptolites are also present." Especially on the presence of one species, *Didymograptus nanus*, a correlation is made with the Upper Arenig, or Skiddaw.

In northwest China the article is by Troedsson[2] with an appendix by Bulman. Troedsson has illustrated and described twenty-five new species of brachiopods, pelecypods, cephalopods, and chiefly trilobites, and has illustrated many more undetermined forms. Among all these not a single known species occurs; also a number of genera are new, so they have little value for specific correlation. In contrast with this condition, in the appendix by Bulman[3] five species of graptolites and one generic form are illustrated and described as follows: *Didymograptus* cf. *superstes* Lapworth, *Climacograptus scharenbergi* Lapworth, *Glyptograptus teretiusculus* (Hisinger) var. cf. *euglyphus* (Lapworth), *Amplexograptus* sp., and *Cryptograptus tricornis* (Carruthers). Several of these occur in the Glenkiln of Great Britain, the Normanskill of New York, the Womble of Arkansas, and the Stringtown and basal Viola of Oklahoma. Also they occur in Sweden, in northwest Nelson in New Zealand, and in Victoria, Australia.

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NORMAN, OKLAHOMA
January 7, 1938

[1] T. H. Yin and C. H. Lu, "On the Ordovician and Silurian Beds of Shihtien, Western Yunnan," *Bull. Geol. Soc. China*, Vol. 16 (1936–1937), pp. 41–56.

[2] Gustaf T. Troedsson, "On the Cambro-Ordovician Faunas of Western Qurugtagh, Eastern Tien-Shan," *The Sino-Swedish Expedition, Pub. 4, Paleontologia Sinica*, New Ser., Bull. 2 (July, 1937), pp. 1–74; 10 pls. (Published by the Geol. Survey of China.)

[3] O. M. Bulman, "Report on a Collection of Graptolites from the Charchak Series of Chinese Turkestan," *ibid.*, Appendix, pp. 1–5.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 2 (FEBRUARY, 1938), PP. 222-228

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available to members and associates.

**Oriskany Sand Symposium*. Appalachian Geological Society, Charleston, West Virginia (1937). 110 pp., maps, sections. Cloth. Price, $3.00.

This book is a compilation of information on the extent, character, and yield of the Oriskany sand, the most recently discovered of the gas-producing horizons in the eastern area.

West Virginia outcrops of the Oriskany (Ridgeley) sandstone, the overlying Huntersville chert, and the underlying Shriver chert are discussed by Paul H. Price. He offers a possible solution to one of the stratigraphic problems of the area by correlating the Huntersville chert with the Corniferous limestone and placing it in the Oriskany group rather than in the Onondaga. This conclusion is based entirely on evidence from sections in West Virginia. The reviewer believes that the evidence from outcrops and wells in Pennsylvania and New York should be carefully considered before the proposed correlation is considered conclusive.

A description of the petrography of the Oriskany and the Corniferous by James H. C. Martens is based on a study of cuttings from twenty-five wells in six West Virginia counties and two wells in Pennsylvania. It is the first published detailed description of these formations as they occur underground in West Virginia. (This paper appeared in *Oil and Gas Journal*, October 1, 1936, p. 21.)

The discovery of oil and gas in the Oriskany sand, and the sequence and importance of later discoveries of gas in Ohio, New York, Pennsylvania, and West Virginia are recorded by Thurman H. Myers, who also ventures predictions as to areas where future discoveries may be expected. He comments briefly on the relation between Oriskany production and structure and gives the seismograph credit for simplifying the task of the prospector in the gas-producing areas of Pennsylvania. He estimates the depth to the Oriskany at various points—as yet undrilled—and voices the opinion of many in this area that, "Whether or not the average producer has faith in the Oriskany sand as the best source for our future gas supply, many of us are agreed that it is the logical prospect before us at this time." A map which shows the fields, and most of the dry holes in the Oriskany, is one of the excellent features of this paper.

One of the most helpful papers is "Devonian Shale and Oriskany Sand Drilling in the States of New York, Pennsylvania, Ohio, West Virginia, and Eastern Kentucky," compiled by Johnson Bennett in coöperation with Coleman D. Hunter, Thurman Myers, and J. E. Billingsley. Pertinent information on most of the wells that have been drilled to the Oriskany sand and of many that were stopped in the Marcellus shale, is tabulated and the well locations are given on a large-scale map.

A supplementary paper compiled by the West Virginia Gas Corporation gives a similar list containing only wells in West Virginia. This paper covers a somewhat longer period and brings the information more nearly to date than does the preceding one.

Stratigraphic and structural details are given in five papers: "Southern West Virginia Cross Sections in Connection with Oriskany Sand Drilling," by J. E. Billingsley; "The Oriskany Sand in Ohio," by J. R. Lockett; "Devonian and Silurian Limestones of Southern West Virginia," by David B. Reger; "Cross Section of Carter County, Kentucky, to Fayette County, West Virginia," by C. E. Krebs; and "Deeper Horizons of West Virginia," by Robert C. Lafferty. Lockett's paper, in addition to stratigraphic information, gives a good summary of production from the Oriskany in Ohio. The paper by Lafferty briefly discusses horizons below the Oriskany which may yield oil or gas. It is to be hoped that similar papers for the northern area, Pennsylvania and New York, will be presented in the near future and that this stratigraphic work will provide a stable foundation for correlations between the areas.

In "Analysis of Oriskany Gas in Kanawa County, West Virginia, with Some Interpretations," Paul H. Price and A. J. W. Headlee not only tabulate analyses of the gas in the two fields here, but also present maps showing by isometric lines the percentages of propane, carbon dioxide, and nitrogen. There is one oil well in one of the fields and they point out that the propane content of the gases in this field increases in the direction of this oil well. They conclude, therefore, that the low propane content of the gas in the other field discourages the hope that commercial oil may exist in that field. They also suggest that the carbon-dioxide content of the gas in one field is supporting evidence for a postulated fault, since the highest percentage of carbon dioxide is found in the gas wells nearest this postulated fault. Both suggestions are interesting, but seem to be merely conjectural, and of present value primarily as suggestions for further investigation.

Two papers on operating practices are included in the symposium: "Cementing Methods," by K. Bolton, and "The Cement Bailer or Sprayer," by Ralph Haddox.

The book is a useful and timely compilation. It makes generally available in compact and usable form much information that had heretofore been scattered and not easily obtainable. We may hope that it is the forerunner of more complete and, in some instances, more studious contributions. In many respects the papers in this volume are reminiscent of some in the early numbers of the BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS whose authors were handicapped not only by scarcity of data but also by the fear that they might disclose something that would benefit a competitor. This may be justified by the present early stage of the Oriskany gas developments and the comparatively short period during which oil geologists have been working on the problems connected with discovery of gas in the Oriskany sand.

ELIZABETH E. STEPHENSON

PITTSBURGH, PENNSYLVANIA
December 8, 1937

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*"Report of the Committee on Sedimentation, 1936–1937," Parker D. Trask, chairman. 128 mim. pp. Obtainable from Division of Geology and Geography, National Research Council, 2101 Constitution Avenue, Washington, D.C. Price, $0.15.

A symposium on recent sediments is the main objective toward which the committee is working. The present report comprises nine brief summary

progress reports on various phases of the problem of recent sediments: C. B. Brown, "Sedimentation Studies by the Soil Conservation Service"; H. B. Milner, "Research by British Scientists during the years 1934–1937"; F. J. Pettijohn, "Mineralogy of Sedimentary Rocks"; H. Rouse, "Nomogram for Settling Velocity for Spheres"; W. H. Twenhofel, "Terminology of the Fine-Grained Mechanical Sediments" and "The Bottom Sediments of Lake Monona, Wisconsin"; F. M. Varney and Lowell Redwine, "A Hydraulic Coring Instrument for Submarine Geologic Investigation"; R. D. Russell and R. E. Taylor, "Bibliography on Roundness and Shape of Sedimentary Particles"; L. Williams, "Classification and Selected Bibliography of the Surface Textures of Sedimentary Fragments." All the reports contain useful lists of pertinent references.

The work of the committee and its reports should be of much interest to most petroleum geologists. All subsurface laboratories would do well to keep in touch with the work of the committee.

DONALD C. BARTON

HOUSTON, TEXAS
December, 1937

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*"Geology of the Muskogee-Porum District, Muskogee and McIntosh Counties, Oklahoma." By CHARLES W. WILSON, JR. With a chapter on "Carboniferous Stratigraphy," by Norman D. Newell. *Oklahoma Geol. Survey Bull. 57* (Norman, 1937). Prepared under coöperative arrangement with the U. S. Geological Survey. 184 pp., 5 figs., 7 pls. 6×9 inches. Paper. Price, $1.10, postpaid.

This report deals chiefly with Muskogee County and includes that part of the county south and west of the Arkansas River and west to include R. 18 E. It also includes T. 14 N., R. 17 E., and that part of T. 15 N., R. 17 E., south of the river. The area is bounded on the south by the Canadian River, which is also the county line. The two northeast townships of McIntosh County are included. Thus the publication of this volume departs from the usual procedure of the Oklahoma Geological Survey since it deals with a stratigraphic unit rather than a geographic unit. The make-up of *Bulletin 57* is also in contrast to former bulletins. A larger and more distinct type and a more pleasing format, combine to make a very legible and readable volume. There are 184 pages, of which 115 deal directly with the geology of the area.

Rocks from the Pitkin limestone of Mississippian age, up to the Taft sandstone in the upper Boggy formation, are exposed in the area. The Quaternary (?) is represented by terrace deposits and river silt.

A short résumé of the surface rocks by Wilson is augmented by a chapter by N. D. Newell in which there is a discussion of each formation and the separate members. Newell is also responsible for 82 detailed measured surface sections given in Appendix B. Much has been done to help straighten out the long discussed correlation of the coal-basin stratigraphy with the Cherokee beds on the north. A correlation chart showing the relation of the strata of this area with the Cherokee of southeastern Kansas is included.

A synopsis of the subsurface stratigraphy down to pre-Cambrian granite, found in at least two wells, is given. Faunal collections are listed from several of the formations. The principal structural axes of the area are shown and their relation to the Ozark uplift is discussed.

A chapter on economic geology includes description and analyses of coal deposits in the area, as well as a history of the oil and gas development. Each oil field, with pertinent facts about it, is treated separately.

A short chapter by Robert H. Dott lists miscellaneous mineral resources of the area, including tables on estimated quantity of sand and gravel, analyses of limestones, location and analyses of shale deposits, location and types of building stone, and reservoir beds and analysis of underground water. Appendix A lists nearly 500 water wells, giving the location, depth, estimated daily capacity, type of water, producing horizon, and other information which will make the volume useful to rural inhabitants in the area.

A geologic map and a correlation chart accompany the volume. The map is unique in Oklahoma Survey maps. It is on a scale of 1 mile to 1 inch and shows all roads and trails. It is printed in three tones, with culture and drainage in black and areal geology in white and green. Twenty-four different horizons are shown in the two colors, yet the different cross-hatch patterns and the three horizons shown in solid green are so carefully chosen that there is no confusion. A northwest-southeast cross section which extends across the entire area is given on the same plate with the map.

Wilson and Newell have added valuable information to Oklahoma geology. The State Geological Survey is to be congratulated on the type of volume and the excellent make-up of the map, as well as on an attempt to make its publications of interest and value to other than the geological profession.

J. L. Borden

Tulsa, Oklahoma
January 10, 1938

RECENT PUBLICATIONS

AUSTRALIA

"Progress of Search for Oil in Australia and Territories," Anon. *Petrol. Times*, Vol. 38 (974) (London, September 9, 1937). *Abstract in *Jour. Inst. Petrol. Tech.*, Vol. 23, No. 169 (London, November, 1937), p. 409 A.

BAHREIN ISLAND

*"Bahrein Island among 15 Largest Oil Producers." *Oil and Gas Jour.*, Vol. 36, No. 33 (December 30, 1937), pp. 127–34; 10 figs. including structure map and cross section.

CALIFORNIA

*"An Upper Pleistocene Fauna from the Baldwin Hills, Los Angeles County, California," by George Willett. *Trans. San Diego Soc. Natural History* (San Diego), Vol. 8, No. 30 (December 15, 1937), pp. 379–406; 2 pls.

*"Properties of California Crude Oils. V—Additional Analyses," by E. C. Lane and E. L. Garton. *U. S. Bur. Mines R. I. 3362* (December, 1937). 21 mim. pp.

FLORIDA

*"Mollusks of the Tampa and Suwannee Limestones of Florida," by W. C. Mansfield. *State of Florida Dept. Conservation* (Tallahassee) *Geol. Bull. 15* (October, 1937). 334 pp., 21 pls. of fossils, 2 faunal distribution charts.

GENERAL

*"Report of the Committee on Sedimentation, 1936–1937," Parker D. Trask, chairman. *Natl. Research Council* (Washington, D.C., October, 1937). Presented at the annual meeting of the Division of Geology and Geography, National Research Council, May 1, 1937. Price, $0.15.

*"Belt Series of the North: Stratigraphy, Sedimentation, Paleontology," by Carroll Lane Fenton and Mildred Adams Fenton. *Bull. Geol. Soc. America* (New York), Vol. 48, No. 12 (December 1, 1937), pp. 1873–1970; 19 pls.; 20 figs.

*"The Marine Cycle of Erosion for a Steeply Sloping Shoreline of Emergence," by William C. Putnam. *Jour. Geol.* (Chicago), Vol. 45, No. 8 (November-December, 1937), pp. 844–50; 2 figs.

GEOPHYSICS

*"Unusual Problems Present in Seismograph Work Abroad," by Joseph L. Adler. *Oil and Gas Jour.* (Tulsa), Vol. 36, No. 33 (December 30, 1937), pp. 75, 302; 3 figs.

"Geophysical Abstracts, 88, January-March 1937," compiled by W. Ayvazoglou. *U. S. Geol. Survey Bull. 895-A* (1937), pp. i–ii, 1–42. Supt. Documents, Govt. Printing Office, Washington, D.C. Price, $0.10.

*"Geophysical Interpretations," by M. S. Blackburn. *Oil Weekly* (Houston), Vol. 88, No. 4 (January 3, 1938). p. 15.

GERMANY

*"Ergebnisse neuer Untersuchungen über Fazies and Bildung von Trias und Jura in Südwest Deutschland" (The Latest Results of the Investigation on the Facies and Formation of the Triassic and Jurassic in Southwest Germany), by Manfred Frank. *Geol. Rundschau* (Stuttgart), Bd. 28, Heft 6/7 (November, 1937), pp. 465–98; 8 figs. Contains stratigraphic cross sections and numerous correlation charts.

Das marine Paläozän und Eozän in Norddeutschland und Sudskandinavien mit einer Zusammenstellung der gesamten Literatur (The Marine Paleocene and Eocene in Northern Germany and Southern Scandinavia, with a Digest of All the Literature), by Theodor Müller. Published by Borntraeger Brothers, Berlin (1937). 124 pp. Price, RM 5.

GREAT BRITAIN

"Stratigraphical and Structural Distribution of Petroleum in Britain," by E. H. Cunningham Craig. *Petrol. Times*, Vol. 38 (972) (London, October, 28, 1937). *Abstract in *Jour. Inst. Petrol. Tech.*, Vol. 23, No. 169 (London, November, 1937), p. 410 A.

"British Drilling Progress," Anon. *Petrol. Times* (London, August 8, 1937), p. 272; (September 11, 1937), p. 339; (September 25, 1937), pp. 400–01. *Abstract in *Jour. Inst. Petrol. Tech.*, Vol. 23, No. 169 (London, November, 1937), p. 409 A.

*"Five Deep Test Wells Are Being Drilled in United Kingdom." *Oil and Gas Jour.*, Vol. 36, No. 33 (December 30, 1937), p. 136; 1 map.

IRAN

"Garh-i-Qaraghuli Oil Field," Anon. *Petrol. Times*, Vol. 38 (975) (London, September 9, 1937). *Abstract in *Jour. Inst. Petrol. Tech.*, Vol. 23, No. 169 (London, November, 1937), p. 409 A.

MEXICO

*"Stratigraphy and Paleontology of the Upper Cretaceous Beds along the Eastern Side of Laguna de Mayran, Coahuila, Mexico," by Ralph W. Imlay. *Bull. Geol. Soc. America* (New York), Vol. 48, No. 12 (December 1, 1937), pp. 1785–1872; 26 pls.; 4 figs.; geologic map and cross sections.

NEWFOUNDLAND

*"Silurian Strata of Notre Dame Bay and Exploits Valley, Newfoundland," by W. H. Twenhofel and R. R. Shrock. *Bull. Geol. Soc. America* (New York), Vol. 48, No. 12 (December 1, 1937), pp. 1743–72; 4 figs.

*"Silurian Strata of White Bay, Newfoundland," by George R. Heyl. *Ibid.*, pp. 1773–84; 2 figs.

NEW MEXICO

*"The Ceja del Rio Puerco: A Border Feature of the Basin and Range Province in New Mexico. I. Stratigraphy and Structure," by Kirk Bryan and Franklin T. McCann. *Jour. Geol.* (Chicago), Vol. 45, No. 8 (November-December, 1937), pp. 801–28; 9 figs.

OKLAHOMA

"Geology of the Muskogee-Porum District, Muskogee and McIntosh Counties, Oklahoma," by Charles W. Wilson, Jr., with a chapter on "Carboniferous Stratigraphy," by Norman D. Newell. *Oklahoma Geol. Survey Bull. 57* (Norman, 1937). Prepared under coöperative arrangement with the U. S. Geological Survey. 184 pp., 5 figs. 7 pls. 6×9 inches. Paper. Price, $1.10, postpaid.

ROCKY MOUNTAIN REGION

*"Analyses of Crude Oils from Some of the More Recently Discovered Rocky Mountain Fields," by Walter Murphy and H. M. Thorne. *U. S. Bur. Mines R. I. 3358* (December, 1937). 24 mim. pp. Includes history and production data of fields.

ROUMANIA

"Interesting Roumanian Structures under Test," Anon. *Petrol. Times*, Vol. 38 (972) (London, August 28, 1937). *Abstract in *Jour. Inst. Petrol. Tech.*, Vol. 23, No. 169 (London, November, 1937), p. 412 A.

RUSSIA

*"Oil Fields of the U.S.S.R., a Descriptive Outline of Their Geography, Geology and Relative Productiveness," by William J. Kemnitzer. *Oil and Gas Jour.* (Tulsa), Vol. 36, No. 33 (December 30, 1937), pp. 72–73; 2 figs.

SOUTH AMERICA

*"Contributions to Paleobotany of South America." Eight papers by Edward W. Berry. *Johns Hopkins University Studies in Geology*, No. 12. 114 pp., 20 pls. Johns Hopkins Press, Baltimore (1937). Price, $2.00.

TEXAS

"Geology and Ground-Water Resources of Webb County, Texas," by J. T. Lonsdale and J. R. Day. *U. S. Geol. Survey Water Supply Paper 778* (1937). 104 pp., 12 pls., 6 figs. Supt. Documents, Govt. Printing Office, Washington, D.C. Price, $0.30.

*"Acid Treatment of Oil Sands in South Texas," by F. B. Plummer. *Oil Weekly* (Houston), Vol. 88, No. 4 (January 3, 1938), pp. 24–30; 4 figs.

VENEZUELA

*"Stratigraphy of the Rio Querecual Section of Northeastern Venezuela," by Hollis D. Hedberg. *Bull. Geol. Soc. America* (New York), Vol. 48, No. 12 (December 1, 1937), pp. 1971-2024; 9 pls.; 2 figs.

WEST VIRGINIA

*"The Monongahela Series in Eastern Ohio," by Wilbur Stout. *Bull. West Virginia Univ.*, Ser. 30, No. 1; *Proc. West Virginia Acad. Sci.*, Vol. 3 (August, 1937), pp. 118–33; 1 fig. and stratigraphic table.

WYOMING

*"History of the Grand Canyon of the Yellowstone," by Arthur David Howard. *Geol. Soc. America Special Paper 6* (November, 1937). 157 pp., 31 figs., 21 pls. Contains geological map of Yellowstone Valley.

*"Analysis of Maverick Springs, Wyoming, Crude Oil." *U. S. Bur. Mines Press Release 6144* (December 31, 1937). 4 mim. pp.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

* *Journal of Paleontology* (Tulsa, Oklahoma), Vol. 12, No. 1 (January, 1938).

"A Restudy of the Tracks of *Paramphibius*," by Kenneth E. Caster
"Ophiurans from the Upper Senonian of South Limburg, Holland," by Charles T. Berry
"Upper Cambrian Faunas of the Cap Mountain Formation of Texas," by Christina Lochman
"Studies of Late Paleozoic Ammonoids," by M. K. Elias
"New Tertiary Mollusks from Western North America," by G. D. Hanna
"*Bothriolepis stensiöi*, a New Devonian Placoderm from Gaspé, Canada," by I. G. Sohn
"Nomenclature of *Lindströmia* Nicholson and Thompson and Its Genotype," by M. Frances Willoughby

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Photo by McDaniel. Courtesy New Orleans Association of Commerce

New Orleans sky line. The 23d annual meeting of the A.A.P.G. will be held in New Orleans, March 16–18.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 2 (FEBRUARY, 1938), PP. 229-237

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

George Elmer Abernathy, Pittsburg, Kan.
R. C. Moore, Eugene A. Stephenson, N. W. Bass
Kenneth A. Ackley, Seminole, Okla.
H. L. Rau, E. O. Markham, E. V. Whitwell
Aldo Ferrando, Houston, Tex.
Ed. W. Owen, Gage Lund, Phil F. Martyn
Kenneth K. Landes, Lawrence, Kan.
Raymond C. Moore, John L. Garlough, Anthony Folger
F. Spencer Withers, Shawnee, Okla.
D. J. Jones, R. C. Lane, J. S. Hudnall
Bennett Frank Buie, New York, N. Y.
John M. Lovejoy, Kirtley F. Mather, Frederick G. Clapp
Herbert V. Lee, Cucuta, Colombia, S.A.
Frank B. Notestein, C. W. Flagler, Howard F. Nash

FOR ASSOCIATE MEMBERSHIP

John Wiley Bolinger, Houston, Tex.
Thomas R. Warrick, H. G. Patrick, Glenn E. Bader
Ray E. Claiborne, Houston, Tex.
K. H. Crandall, Douglas Weatherston, Richard W. Camp
Wallace Woodrow Hagan, Detroit, Mich.
P. Hastings Keller, Harold R. Wanless, F. W. DeWolf
John Huner, Jr., University, La.
H. V. Howe, R. J. Russell, C. J. Roy
Victor Henry King, Los Angeles, Calif.
A. J. Tieje, W. D. Waltman, R. O. Swayze
Jack D. Mullinax, Denver, Colo.
J. H. Johnson, B. H. Parker, W. A. Waldschmidt
Donald L. Norling, Dodge City, Kan.
Leo R. Fortier, R. E. Shutt, R. B. Roark
Homer Whitman Patnode, Washington, D. C.
Arthur A. Baker, Thomas A. Hendricks, M. N. Bramlette
J. B. Petta, Beaumont, Tex.
W. M. Winton, E. W. Shuler, John D. La Touche
Elizabeth Earl Stephenson, Pittsburgh, Pa.
K. C. Heald, R. E. Somers, E. A. Eckhardt

Edwin Frank Ustynik, El Dorado, Ark.
Roy T. Hazzard, Cecil L. Morgan, W. B. Weeks
Clyde Wayne Alexander, El Dorado, Ark.
W. B. Weeks, Paul E. Nash, Joseph Purzer
Lloyd J. Broussard, Houston, Tex.
Kenneth Dale Owen, R. C. Bowles, L. W. MacNaughton
Jack Chambers, Houston, Tex.
A. R. Mornhinveg, Merle C. Israelsky, John S. Ivy
William Edgeworth Dougherty, Midland, Tex.
Vaughn C. Maley, J. Ben Carsey, Robert H. Cuyler
Noel W. Engel, Mattoon, Ill.
Kenneth L. Gow, Coleman D. Hunter, Arthur C. McFarlan
Theodore Gunter Glass, Tulsa, Okla.
Graydon H. Laughbaum, Linn M. Farish, Frederic A. Bush
John Harvey Herd, Midland, Tex.
Hewlett A. Russell, John Emery Adams, Charles A. Mix
William Joseph Hilseweck, Oklahoma City, Okla.
Charles E. Decker, V. E. Monnett, Robert H. Dott
Edward Archibald Huffman, Wichita, Kan.
Howard S. Bryant, Harold O. Smedley, Edward A. Koester
Louis Guy Huntley, Pittsburgh, Pa.
J. R. Wylie, Jr., R. E. Sherrill, L. G. Huntley
Philip M. Konkel, Houston, Tex.
Will F. Earl, Horace D. Thomas, G. W. Carr
Sam Stewart, Los Angeles, Calif.
John L. Porter, U. S. Grant, E. K. Soper
Robert Neil Williams, Jr., Taft, Calif.
W. F. Barbat, Rollin Eckis, W. D. Kleinpell
Robert Busch Wing, Tulsa, Okla.
R. E. Shutt, Fanny C. Edson, Sherwood Buckstaff

FOR TRANSFER TO ACTIVE MEMBERSHIP

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Rollin Eckis, Albert Gregersen, Chester Cassel
Bernhard E. Bremer, Paris, Tex.
G. W. Schneider, S. G. Gray, D. J. Munroe
Emmett Perry Tatum, Houston, Tex.
F. W. Rolshausen, L. P. Teas, J. E. LaRue

TWENTY-THIRD ANNUAL MEETING, NEW ORLEANS, LOUISIANA, MARCH 16–18, 1938

GENERAL COMMITTEE

Chairman, R. A. Steinmayer, Head, Department of Geology, Tulane University
Richard W. Leche, Governor, State of Louisiana
Robert S. Maestri, Mayor, City of New Orleans
William G. Rankin, Commissioner, Louisiana Department of Conservation
C. L. Moody, Vice-President, American Association of Petroleum Geologists
B. W. Blanpied, President, Shreveport Geological Society
C. I. Alexander, President, South Louisiana Geological Society
Pierce Cline, President, Centenary College of Louisiana
Harold A. Gaudin, S.J., President, Loyola of the South
Rufus C. Harris, President, Tulane University
James M. Smith, President, Louisiana State University
J. A. Shaw, Head, Minerals Division, Louisiana Department of Conservation
H. V. Howe, Director, School of Geology, Louisiana State University
Ben J. Williams, President, New Orleans Association of Commerce
J. A. Bechtold, Vice-President and Treasurer, Standard Oil Company of Louisiana
Wilson T. Lundy, Vice-President, Freeport Sulphur Company
W. H. McFaddin, President, Southland Royalty Company
J. E. Ralston, Vice-President, Pan-American Petroleum Corporation
J. C. Munroe, Division Manager, Shell Petroleum Company
H. G. Meador, Division Manager, Gulf Producing Company

CHAIRMEN OF COMMITTEES

General chairman, R. A. Steinmayer, Tulane University, New Orleans
Technical program, C. L. Moody, Ohio Oil Company, Shreveport
Finance, R. A. Steinmayer
Entertainment, Carroll E. Cook, 1403 Octavia Street, New Orleans
Reception, C. I. Alexander, Magnolia Petroleum Company, Lake Charles
Registration, John F. Mahoney Union Sulphur Company, Sulphur Mines
Publicity, C. K. Moresi, State Geological Survey, Civil Court Bldg., New Orleans
Hotels, J. Edward Lytle, 5520 Loyola Street, New Orleans
Field trips, Roy T. Hazzard, Gulf Refining Company, Shreveport
Transportation, Tatham R. Eskrigge, 1326 Harmony Street, New Orleans
Golf, Donald Goodwill, Jr., Department of Conservation, New Orleans

The American Association of Petroleum Geologists will hold its twenty-third annual meeting at the Roosevelt Hotel, New Orleans, March 16–18, 1938. Also, the Association's Division of Paleontology, the Society of Economic Paleontologists and Mineralogists, will hold its twelfth annual meeting, March 17, and the Association's affiliate, the Society of Exploration Geophysicists, will hold its ninth annual meeting, March 14–16.

Various committee meetings are scheduled on the days immediately preceding the technical program: particularly, meetings of the executive committee on Monday and Tuesday, the 14th and 15th; the annual meeting of the general business committee on Tuesday, the 15th; and the research committee round-table discussion of "Time of Formation and Accumulation of Petroleum" on Tuesday evening, the 15th.

Five post-convention field trips are planned: (1) 2-day trip into Smith and Wayne counties, Mississippi, to study the Oligocene-Miocene problem; (2) 1-day trip to Lake Washington sulphur mine; (3) 1-day trip to Avery Island salt mine; (4) 1-day trip to see Gulf Coast drilling operations; and (5) 1-day sight-seeing trip to Gulf Coast oil fields. Also a post-convention trip to Cuba via Tampa and Havana may be arranged for those who can make their plans in advance of the meeting. Inquiries should be directed to Roy T. Hazzard, Gulf Refining Company, Shreveport, Louisiana.

Low round-trip fares are in effect on the railroads. No special convention certificates are to be used. Information about rates, stop-overs, return limits, diverse routing, should be obtained in advance from local station agents.

Hotel reservations should be made in advance of the convention. Communicate with the hotel of your choice and request confirmation of your reservation.

HOTEL ACCOMMODATIONS

Hotel and Blocks from Roosevelt		*Total Rooms*	*With Bath or Shower*		*Parlor Suites*		
			Single	*Double*	*1 Room*	*2 Rooms*	*3 Rooms*
Roosevelt		700	\$3.50–\$6	\$4.50–\$9	\$15–\$18	\$24–\$27	\$32–\$36
St. Charles	2½	500	\$3.00–\$5	\$5.00–\$8	\$10–\$18		
DeSoto	3	250	\$3.00–\$5	\$4.00–\$7			
Jung	5½	700	\$3.00–\$4	\$4.00–\$8	\$10–\$12	\$15–\$18	
LaSalle*	2	100	\$2.00–\$3	\$3.25–\$4			
Monteleone	3½	600	\$3.00–\$4	\$4.00–\$7			
New Orleans	3½	325	\$3.00–\$4	\$4.00–\$7			

* At LaSalle: rooms without bath, single, \$1.50–\$1.75; double, \$2.50–\$3.00.

TECHNICAL PROGRAM

Regional stratigraphic and structural titles offered for the technical program include the following Coastal Plain papers.

Warren B. Weeks, "South Arkansas Stratigraphy with Special Emphasis on the Older Coastal Plain Beds"

M. C. Israelsky, "Cretaceous and Late Comanche Stratigraphy of the Arkansas-Louisiana-East Texas Area"

R. T. Hazzard, A. M. Lloyd, C. I. Alexander, "North-South Cross Section, Arkansas to the Gulf of Mexico"

Urban B. Hughes, "Detailed Study of the Buccatuna-Vicksburg Contact in Smith County, Mississippi"

B. W. Blanpied, "Salt Mountain Limestone, Alabama"

B. W. Blanpied and R. T. Hazzard, "Stratigraphy of Wayne County, Mississippi"

Olive C. Postley, "Oil and Gas Possibilities of the Atlantic Coastal Plain from New Jersey to Florida

H. B. Stenzel, "The Yegua Problem"

C. Wythe Cooke and Arthur C. Munyan, "Stratigraphy of the Coastal Plain of Georgia"

L. W. Stephenson and W. H. Monroe, "Mappable Units in the Cretaceous of Mississippi and Alabama"

M. A. Hanna and Donald Gravell, "Tertiary Zones of Correlation through Mississippi, Alabama, and Florida"

O. R. Champion, "Subsurface Cross Section of the Cretaceous of South Texas"

Alexander Deussen and Kenneth Owen, "Schlumberger Interpretation of Gulf Coast Typical Section"

J. B. Reeside, Jr., and L. W. Stephenson, "Comparison of the Upper Cretaceous Deposits of the Interior and Gulf Regions"

Robert H. Cuyler, "The Travis Peak Formation of Central Texas"

Julia Gardner, "Notes on the Middle Eocene of the Western Gulf Province"

Arthur G. Hutchinson, "Upper Eocene Unconformity of Trindad"

Chalmer J. Roy, "Type Locality of the Citronelle Formation, Citronelle, Alabama"

W. C. Spooner, "History of Development of Geologic Knowledge in North Louisiana and South Arkansas with Particular Reference to Well Sampling and Use of Schlumberger Logs"
B. W. Blanpied and R. T. Hazzard, "Structure and Stratigraphy of the Hatchetigbee Anticline and Jackson Fault, Alabama"
C. L. Moody, "Earlier Mesozoic History of the Northern Gulf Region"

Papers describing in detail the geology of individual oil and gas pools are being contributed largely from the Mid-Continent and Gulf Coastal Plain areas; California, the Rocky Mountain states and the East are also represented. The following titles are in the hands of the program chairman.

J. S. Ivy, "Rodessa Oil Field"
A. M. Lloyd and R. T. Hazzard, "Résumé of Louisiana Upper Cretaceous Fields"
E. B. Hutson, "Cotton Valley Field, Louisiana"
Sidney Packard, "The Sligo Field, Louisiana"
V. P. Grage and E. F. Warren, "The Sugar Creek-Lisbon Structure"
A. F. Crider, "Bellevue Dome, Louisiana"
C. C. Clark, "Sugar Creek Gas Field, Louisiana"
G. D. Thomas, "Carterville-Shongaloo-Sarepta Area, Louisiana"
H. R. Kamb, "Bear Creek, Simmsboro, and Driscoll Gas Fields, Louisiana"
Warren B. Weeks, "Schuler Field, Union County, Arkansas"
H. N. Toler and W. H. Monroe, "The Jackson Gas Field, Mississippi"
Dean Metts, "The Roanoke Field, Louisiana"
Carroll E. Cook, "Darrow Dome, Ascension Parish, Louisiana"
P. H. O'Bannon and Charis R. Miller, "Anahuac, Chambers County, Texas"
Ed. J. Hamner, "Amelia Field, Jefferson County, Texas"
J. C. Poole and Kenneth D. Owen, "Placedo Field, Victoria County, Texas"
Phil Martyn, "Refugio Field, Refugio County, Texas"
J. C. Miller and W. E. Greenman, "Time of Accumulation of Oil, Manvel Field, Brazoria County, Texas"
C. E. Manion, "Bosco Oil Field, Louisiana"
G. S. Buchanan, "Cheneyville Oil Field, Rapides Parish, Louisiana, and Its Relation to the Areas of Mother Salt Deposition"
Boyd Best, "The Lopez Field of Webb and Duval Counties, Texas"
Harvey Whitaker, "The Hoffman Field of Duval County, Texas"
W. D. Anderson and U. R. Day, "Monument Oil Field, New Mexico"
R. L. Denham, "Means Pool, Andrews County, Texas"
Allen W. Tillotson, "The Olympic Pool, Hughes and Okfuskee Counties, Oklahoma"
Frederic A. Bush, "Geology of the Moore Field, Cleveland County, Oklahoma"
Addison Young and Max David, "Geology of the Goldsmith Pool, Texas"
Wayne Jones, "Cayuga Oil Field, Texas"
J. E. Hupp, "The Cut Bank Oil Field, Montana"
W. T. Nightingale, "Petroleum and Natural Gas in Non-Marine Sediments of the Powder Wash Field in Northwest Colorado"
Frank W. DeWolf, "Paleozoic Beds in the Baker-Glendive Well in Southeastern Montana"
R. G. Reese, "The El Segundo Oil Field, Los Angeles Basin, California"
E. J. Bartosh, "The Wilmington Oil Field, Los Angeles Basin, California"

In the Mid-Continent and Rocky Mountain provinces noteworthy contributions to regional stratigraphy and structure are the following.

Philip B. King, "Paleogeography and Correlation of West Texas Permian"
C. C. Albritton, "Geology of Malone Mountain, Hudspeth County, Texas"
C. E. Dobbin, "Geologic Structure of Part of Petroleum Reserve No. 7, Washington County, Utah"
Samuel G. Lasky, "A Newly Discovered Section of Trinity Age in Southwestern New Mexico"
F. B. Plummer and R. C. Moore, "Stratigraphy and Structure of the Older Carboniferous Rocks on the Llano Uplift in Central Texas"
Clark Millison, "Subsurface Study of the North Flank of the Wichita Mountains, Oklahoma"
George Norton, "The Permian Red Beds of Kansas"
Roy Hall, "History of the Central Kansas Uplift"
Marvin Taylor, John Garlough, "Geology of the Southwest Kansas Gas Area"
Robert Roth, "The Triassic Period in the United States"

From the eastern states come the following contributions.

J. R. Lockett, "Structural Significance of the Cincinnati Arch"
Kendall E. Born, "A Lower Ordovician Sand Horizon in Middle Tennessee"

In a brief symposium on current developments in various districts the following authors and titles will be presented.

A. H. Bell, "Illinois Developments during 1937"
Arthur C. Munyan, "Recent Petroleum Activities in the Coastal Plain of Georgia"
H. P. Bybee, "Recent Developments in West Texas and New Mexico"
Rycroft G. Moss, "Recent Kansas Developments"
Edwin H. Hunt, "New Developments in the Rocky Mountain Area"
R. B. Grigsby, "South Louisiana Current Developments"
H. K. Shearer, "Recent Developments in North Louisiana and South Arkansas"
Stuart Mossom, "South Texas Developments in 1937"
Basil B. Zavoico, "Developments in Russia during 1937"

Contributions of general scope are as follows.

F. H. Lahee, "Wildcat Drilling in 1937"
R. J. Schilthuis, "Behavior of Fluids in Oil Reservoirs"
R. J. Schilthuis, "Connate Water"
J. M. Frost, III, "The Geologic Aspect of Heaving Shales on the Gulf Coast"
Stanley C. Herold, "Criteria for Determining the Time of Accumulation under Special Circumstances"
George A. Wilson, "The Role of the Petroleum Geologist in the Development of the Law of Oil and Gas"
F. B. Plummer, "Oil Reservoirs"
John L. Rich, "Graben Faulting and Associated Phenomena"
Frank G. Miller and H. C. Miller, "Résumé of Problems Relating to Edgewater Encroachment in Oil Sands"
R. T. Hazzard, "Résumé of Geophysical Activities in North Louisiana and South Arkansas"
T. C. Hiestand, "Studies of Insoluble Residues from the 'Mississippi Lime' of Central Kansas"

R. Dana Russell, "A Test of Petrographic Correlation of Oil Sands in the Gulf Coast"

William L. Horner, "Sand Evaluation by Core Analysis"

J. Brian Eby, "Relation of Petroleum Exploration and Discovery to the Petroleum Industry"

Michel T. Halbouty, "Effects of Tides, Winds, and Barometric Pressures on Gulf Coast Production"

Ralph E. Taylor, "A Contribution to Salt-Dome Terminology"

Photograph from New Orleans Association of Commerce

HEART OF OLD NEW ORLEANS

The Place d'Armes, where the Mississippi Valley development had its beginning in 1718, when New Orleans was laid out by Bienville.

C. L. Moody, chairman of the technical program committee, announces that Governor Richard W. Leche has consented to welcome the Association at the opening of the meeting. A short address will be delivered by Ernest O. Thompson, member of the Texas Railroad Commission and chairman of the Interstate Oil Compact. N. H. Darton, honorary member of the Association, will read a paper on "Tectonics in the Southwest." J. E. Pogue, vice-president of the Chase National Bank, will speak on "Economic Aspects of Drilling."

The annual J. Wallace Bostick golf tournament will be held at the New Orleans Country Club, at 1:00 P.M., March 17. In addition to the Bostick cup of the Association, ten trophies have been donated through the local committee. The chairman of the golf committee, Donald Goodwill, Jr., Department of Conservation, 126 Civil Court Building, New Orleans, to whom entries should be sent, makes this request of A.A.P.G. members: "As you know, each year the Association invites guest players to participate in this tournament, the guests being representatives and friends of the oil fraternity from various places. Therefore I should appreciate your furnishing me the names and addresses of the people whom you desire to be invited to play this year."

The entertainment committee is planning two outstanding features for both men and women. 1. "A Night on the Mighty Mississippi," will be a repetition, with variations, of the boat ride on the Steamer *Capitol*, which was a memorable experience of the fifteenth annual meeting in 1930. This is scheduled for the night of March 16. There will be dancing and the charge is $1.00 per person. 2. The dinner-dance is to be on March 17 in the Grand Ball Room of the Roosevelt. The charge is $3.00 per plate including dancing and floor show. Dinner is at 7:30, floor show at 9:45, and dancing at 10:15 P.M. For those who prefer dancing only, the charge is $1.50 per couple.

LADIES COMMITTEE

Chairman, Mrs. R. A. Steinmayer

New Orleans members

Mrs. Carroll C. Cook	Mrs. W. H. McFadden
Mrs. Tatham R. Eskrigge	Mrs. C. K. Moresi
Mrs. Edward J. Lytle	Mrs. E. H. Thaete, Jr.

State of Louisiana members

Mrs. B. W. Blanpied, representative, Shreveport Geological Society
Mrs. C. I. Alexander, representative, South Louisiana Geological Society

A.A.P.G. members

Mrs. H. B. Fuqua	Mrs. Ira H. Cram
Mrs. C. L. Moody	Mrs. Ralph D. Reed

Entertainment for ladies includes a St. Patrick's Day luncheon on Thursday noon at the Roosevelt Hotel, a walking tour of the Vieux Carré in the afternoon, and a tea at the home of Mrs. W. H. McFadden on Friday.

The twenty-third annual meeting will attract many geologists and friends of the Association. New Orleans is an especially interesting convention city. The Gulf Coast and the large wildcat region east of the Mississippi River are being carefully explored by the petroleum industry. The technical program at New Orleans will be of timely importance. All those planning to attend should make certain of the accommodations they desire by communicating immediately with the hotel of their choice and by requesting the hotel to confirm the reservation. After arrival in New Orleans, prompt registration is requested at the convention counter for securing tickets for round-table research dinner, banquet, dance, trips, golf, and other entertainment. It is particularly important that the ladies register for the several events prepared especially for them.

Other information may be obtained from the committee chairmen or from the general chairman of the A.A.P.G. twenty-third annual meeting, Department of Geology, Tulane University, New Orleans, Louisiana.

R. A. STEINMAYER

ASSOCIATION COMMITTEES

EXECUTIVE COMMITTEE

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Ira H. Cram, *secretary*, Tulsa, Oklahoma
Ralph D. Reed, Los Angeles, California
C. L. Moody, Shreveport, Louisiana
W. A. Ver Wiebe, Wichita, Kansas

GENERAL BUSINESS COMMITTEE

Harold W. Hoots (1938), *chairman*, Richfield Oil Corporation, Los Angeles, California
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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 2 (FEBRUARY, 1938), PP. 238-240

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

JOSEPH E. MORERO, head of the geological department of the Skelly Oil Company, has returned to Tulsa after spending 5 weeks in the Dominican Republic.

ALFRED C. LANE, Pearson professor of geology and mineralogy, emeritus, at Tufts College, gave a lecture on the subject, "Does Mother Earth Show Her Age?" before the University Club in Boston on November 23.

RALPH A. KOENIG, formerly with The Texas Company at Hobbs, is now with The Ohio Oil Company, Hobbs, New Mexico.

CHARLES F. HEWETT, who was formerly with the Standard Oil Company in South America and is now chief geologist for the Superior Oil Company, 418 National Bank of Tulsa Building, Tulsa, was married on October 10, 1937, to Miss Anne Hagerman Shoup, of Colorado Springs.

D. DALE CONDIT may be addressed in care of the Standard Vacuum Oil Company, Room 1476, 26 Broadway, New York City.

E. A. OBERING, who was formerly with the Bataafsche Petroleum Mij. at The Hague, Holland, is now permanently located in Houston, Texas, with the Shell Petroleum Corporation.

C. L. LARSON, Stanolind Oil and Gas Company, has recently been transferred to Wichita, Kansas.

JUNIUS HENDERSON, for 30 years curator of the museum at the University of Colorado, died on November 4 at the age of 72 years.

PAUL H. JAMISON, JR., Sun Oil Company, Beaumont, Texas, and MAURINE HUSBAND, assistant to Louis Roark, Tulsa, were married, December 23.

HARRY CROCKETT may be addressed in care of The Ohio Oil Company, Great Bend, Kansas.

F. A. MELTON, of the geology faculty at the University of Oklahoma, spoke before the Oklahoma City Geological Society, January 10, on the subject, "Aërial Photography as Applied to Geology."

T. NELSON DALE, formerly professor of geology at Vassar College and at Williams College and for 28 years with the United States Geological Survey, died on November 16 at the age of 92 years.

R. A. McCULLOUGH is now at Great Bend, Kansas, with The Ohio Oil Company.

DEAN A. MCGEE, vice-president of Kerlyn Oil Company, and former chief geologist of Phillips Petroleum Company, delivered a series of four

lectures on petroleum geology, January 4–7, 1938, to students and faculty members of the University of Kansas. The talks were sponsored by the Department of Geology.

WALLACE C. THOMPSON, General Crude Oil Company, spoke before the weekly luncheon of the Houston Geological Society, January 6, on "Geological Cross Sections of Texas."

HENRY V. HOWE, Louisiana State University, was the speaker at a meeting of the Shreveport Geological Society, January 7. His subject dealt with his observations concerning the geology of Russia and general conditions prevailing in that country.

W. P. JENNY, consulting geologist and geophysicist, Houston, has moved his office to 908 Sterling Building.

A new geological map of Alberta, compiled by J. A. ALLAN of the department of geology at the University of Alberta, has been published by the Alberta Department of Lands and Mines. The map is printed in fifteen soft tints, each color representing a certain division of geological time. On the black base is shown the geography; the geological boundaries; the culture, including the township and range lines; all railways; cities and several towns.

WALTER H. BUCHER, of the University of Cincinnati, is a vice-president and chairman of Section E, geology and geography, of the American Association for the Advancement of Science.

A. E. MCKAY, Atlantic Refining Company, has moved from the Shreveport district to Midland, Texas.

HAROLD JENKINS is now with the Kerlyn Oil Company, 2009 First National Building, Oklahoma City, Oklahoma.

A. C. DAHL, Shell Petroleum Corporation, has changed his address from Pampa, Texas, to Shell Petroleum Corporation, Box 476, Centralia, Illinois.

GEORGE R. WOOD has changed his address from 421 Second Street Northeast, Hampton, Iowa, to Apartado Postal 323, Barranquilla, Colombia, S. A.

MERWIN G. EDWARDS has been made chief geologist in the SanJoaquin Valley for the Shell Oil Company. He replaces FRANK S. HUDSON, who has been transferred to the Los Angeles headquarters.

MARVIN LEE, formerly technical advisor to the Kansas state corporation commission, has resigned to enter consulting geological practice.

J. BRIAN EBY, consulting geophysicist, was speaker at the Houston Geological Society, January 13, on "Relation of Petroleum Exploration and Discovery to Reserves."

KARL H. SCHMIDT, formerly with the American Askania Corporation, Houston, is now connected with Kadane, Incorporated, Wichita Falls, Texas, in the capacity of geologist and geophysicist.

DARSIE A. GREEN spoke before the Tulsa Geological Society, January 17, on "Major Divisions of the Permian and Geologic History of Western Oklahoma."

Lyman C. Dennis, who received his Master of Science degree at the University of Minnesota in 1936, has been employed by the Pure Oil Company for geological work at Olney, Illinois.

Newly elected officers for the West Texas Geological Society are: president, H. A. Hemphill, Magnolia Petroleum Company; vice-president, W. D. Anderson, Amerada Petroleum Company; secretary-treasurer, W. C. Fritz, Skelly Oil Company.

Charles Gill Morgan, vice-president of the United Geophysical Company of Pasadena, left Los Angeles, January 6, by plane for a 6-weeks visit to South America and the British West Indies.

At a meeting of the Rocky Mountain Association of Petroleum Geologists in Denver, R. H. Beckwith presented a paper, "Structure of the Southwest Margin of the Laramie Basin."

Paul L. Vaudoit is now engaged in the practice of consulting petroleum engineering with office and residence at 2229 Del Monte Drive, Houston, Texas.

J. C. Williams spoke on his 13 years in China with The Texas Company at a meeting of the West Texas Geological Society, January 11.

W. C. Rauch is employed in a consulting capacity for the Union Oil Company of California and stationed at Scotts Bluff, Nebraska.

The following papers composed the technical program of the annual meeting of the Branner Geological Club, held on January 14, 1938, at the California Institute of Technology, Pasadena, California: "Oscillations in Southern California Beaches," by U. S. Grant, associate professor of geology, University of California at Los Angeles, and F. P. Shepard, associate professor of geology, University of Illinois; "Shifting Sea Bottoms along the California Coast," F. P. Shepard; "Notes on the Paleozoic of Eastern California," by John C. Hazzard, geologist, Union Oil Company; "Some Aspects of Geologic Work," by Joseph L. Gillson, development department of DuPont De Nemours and Company; "Modern and Ancient Asia Minor," by John H. Maxson, division of the geological sciences, California Institute of Technology.

The Panhandle Geological Society, Amarillo, Texas, met on January 13 to hear a discussion of "The Past and Present of Areal Geology in the Panhandle," by C. Don Hughes. The meeting was held in a home-theater at the author's residence in Amarillo, and the subject was illustrated with motion pictures.

John M. Muir, chief geologist of Island Exploration Company, Ltd., recently died in a hospital at Sydney, Australia. His field headquarters for the past year had been Daru, Papua.

The Mid-Continent Section of the American Institute of Mining and Metallurgical Engineers met at Tulsa, January 24. The papers presented were A. I. Levorsen, "Need and Use of Light Rotary Drilling Rigs for Geologic Exploration," and Carl White, "Evolution of Portable Rig for Exploratory Drilling."

Arthur W. Duston, geologist and president of the Commonwealth Royalties Company, Tulsa, died on February 2, at the age of 51 years.

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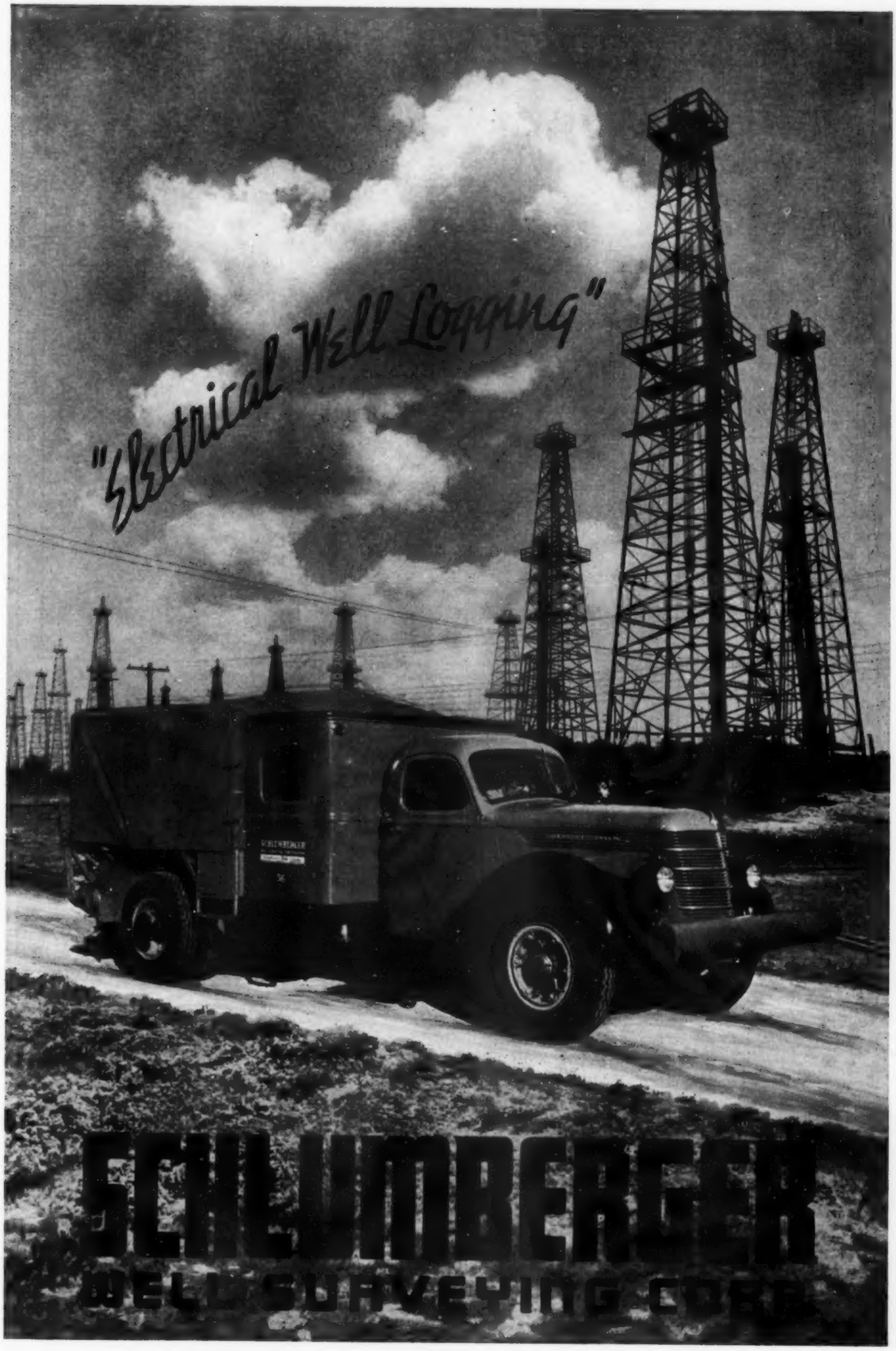
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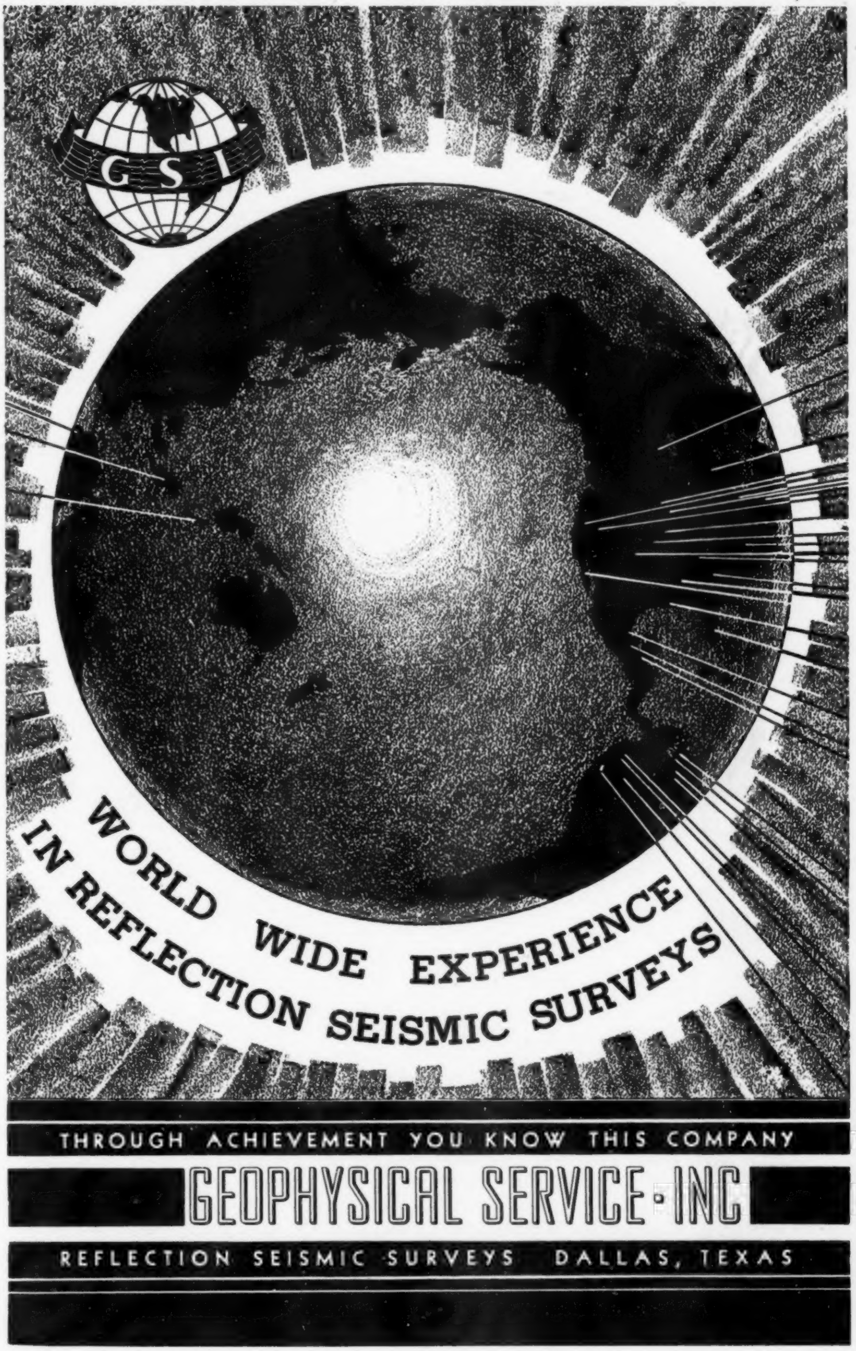
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